EFFECTS OF AREAS CLOSED TO BOTTOM TRAWLING ON FISH AND INVERTEBRATE SPECIES IN THE EASTERN BERING SEA

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ABSTRACT

The Bering Sea is a productive ecosystem with some of the most important fisheries in the United States. Constant commercial fishing for groundfish has occurred since the 1960s. The implementation of areas closed to bottom trawling to protect critical habitat for fish or crabs resulted in successful management of these fisheries. The efficacy of these closures on non-target species is unknown.

This study determined if differences in abundance, biomass, diversity and evenness of dominant fish and invertebrate species occur among areas open and closed to bottom trawling in the eastern Bering Sea between 1996 and 2000. This study represented four areas: two within Bristol Bay closed areas and two within comparable fished areas.

Total abundance and biomass were not significantly different among fished and closed areas or between pre-closure (1990-1994) and post-closure (1996-2000) years. Diversity and evenness were greater in fished areas than closed areas. The biomass of some functional feeding groups (i.e. piscivores, detritivores) of species decreased when compared among areas and in pre-closure versus post-closure years while others increased. These results support the need for continued research and monitoring of eastern Bering Sea closed areas to determine recovery time and the efficacy of closures as a management tool.

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INTRODUCTION

Fisheries management is based on management of individual species (Beamish and Mahnken 1999). This single-species management approach is based on population dynamics and life-history characteristics of individual target species (Davis 1989). In the past decade fisheries management, as well as other conservation efforts, has moved from single-species conservation to an ecosystem-based approach (Beamish and Mahnken 1999; Trites et al. 1999; Witherell 1999). Ecosystem-based management is an approach for managing fisheries that includes all major components of the ecosystem (NRC 1999). This type of management combines habitat values, a multispecies perspective, and commitment to the understanding of ecosystem processes (NRC 1999).

Marine protected areas (MPAs), one technique for managing fisheries, are widely suggested to protect multiple species and complex ecosystems while providing resilience to overexploitation and reducing the risk of collapse of stocks (Guenette et al. 1998) (see Appendix 1 for MPA definitions). Evidence indicates that any area closed to fishing can potentially exhibit many management benefits when clear objectives are formulated. Adjacent unprotected areas enhance commercial catches via emigration, increase in abundance, and increase in fish size (Roberts and Polunin 1992; Bohnsack 1993; Dugan and Davis 1993; Piet and Rijnsdorp 1998). Maintenance of essential fish habitat and habitat quality, protection of spawning stocks, and increase of recruits may occur by preservation of fishing stocks (DeMartini 1993). Restoration and increase of fishery yields may also result (Dugan and Davis 1993). Protected areas may demonstrate an increase in reproductive output and species diversity when compared to adjacent unprotected areas (Schmidt 1997; Roberts 1998) as well as an increase in abundance and biomass of species (Polunin and Roberts 1993). Areas closed to fishing may presumably enhance a return to a more natural species composition, age structure, spawning potential and genetic variability of stock (Bohnsack and Ault 1996).

The Bering Sea is known as one of the most important and productive ecosystems in the world (Pennoyer et al. 1999). It is a shallow continental shelf divided into three domains, commonly referred to as inner, middle, and outer shelves, by depth, and corresponding temperature and salinity (Favorite 1974). These three domains (Table 1) have distinctive hydrographic, circulation, and planktonic community characteristics (Cooney and Coyle 1982; Schumacher and Stabeno 1998).

The United States portion of this productive system currently has eleven time and area closures and regulations that function as protected areas (Figure 1). While most of these closures were implemented to protect juvenile and spawning fishes or crabs, often all life-history stages were targeted for protection. The current regulations have been adopted because of a long history of fisheries management in the eastern Bering Sea (Table 2). These areas fall under the traditional definition of marine protected areas developed by the World Conservation Union (Kelleher and Kenchington 1992).

Among the various closed areas, specific locations in the Bering Sea offer the opportunity to test the paradigms of marine protected areas. The necessary criteria for testing the effectiveness of closed versus open fishing areas are available and include standardized trawl data, similar environment, e.g. bottom type, depth and shelf habitat (Table 1), and similar closure time (Table 2).

Two areas were closed in the eastern Bering Sea, in 1995, to protect red king crab stocks (*Paralithodes camtschaticus*), a target species, and surrounding critical habitat as a precautionary approach to managing fisheries and to supplement ongoing traditional (single-species) management practices and historical closures (NPFMC 1997). Together the Nearshore Bristol Bay Closure Area (NBBCA) and the Bristol Bay Red King Crab Savings Area (RKCSA) (Figure 1) comprise more than 23,000 nmi^2 of marine habitat (Witherell and Pautzke 1997; Ackley and Witherell 1999). Bottom trawling and scallop dredging are currently prohibited year-round in both areas, although pot fishing for Pacific cod (*Gadus macrocephalus*) and crab and some long-lining for Pacific halibut (*Hippoglossus stenolepis*) and Pacific cod do occur (Witherell 1999). These areas have similar closure histories and protect similar species assemblages by outlawing bottom trawling (Witherell and Pautzke 1997; Ackley and Witherell 1999).

Portions of the NBBCA and the RKCSA were closed from 1959-1983 to minimize conflicts with tanglenet and crab pot fisheries (Ackley and Witherell 1999). The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), established in 1976, prohibited fishing in Bristol Bay by vessels of foreign registration except under special authorization (Witherell and Pautzke 1997). In 1983 all of Bristol Bay was re-opened to revitalize the domestic trawl fisheries (Ackley and Witherell 1999). In 1987 area 512 (Figure 1), which is now contained within the NBBCA, was closed to trawling year-round to protect red king crab mating grounds (Witherell and Pautzke 1997; Ackley and Witherell 1999). Area 508 (Figure 1), comprising nearshore areas within the NBBCA, was closed in 1995 to protect juvenile crab habitat (Ackley and

Witherell 1999). In 1995 Amendment 37 of the North Pacific Fisheries Management Council (NPFMC) prohibited all trawling in nearshore Bristol Bay to protect juvenile red king crab and critical habitat that was vulnerable to trawling (Witherell and Pautzke 1997). The NBBCA was established in 1997 to protect red king crab across all life stages (Livingston and Witherell 1999).

From 1989 through 1994 area 516 (Figure 1), which consists of half of the RKCSA along with other waters, was closed annually to trawling between April 14 and June 16 (Witherell and Pautzke 1997; Ackley and Witherell 1999). In 1994, the red king crab pot fishery was closed in Bristol Bay due to decreased abundance (Ackley and Witherell 1999). Closure to fishing was implemented on January 20, 1995, in the RKCSA as an emergency rule, because the area was recognized as having a high concentration of adult females, yet also high bycatch (Ackley and Witherell 1999). Amendment 37 of the NPFMC closed it permanently in June of 1996 (NPFMC 1997).

The NBBCA accounts for 19,000-nmi^2 of protected habitat and is located in the center of red king crab stock distribution (Otto 1981). The protected area ranges from 50 m to 100 m in depth (Favorite 1974) with an average depth of 63 m and contains mud and sand bottom sediments (Smith and McConnaughey 1999; Table 3). Only a small portion in the northern part of the bay (159° to 160°W and 58° to 58°43'N) is open annually to bottom trawling for yellowfin sole (*Limanda aspera*) from April 1 to June 15 when very few red king crab are taken as bycatch (Livingston and Witherell 1999).

The RKCSA accounts for approximately 4,000-nmi^2 of critical habitat that is important to molting and mating king crabs (NPFMC 1996). This habitat includes depths of approximately 50 m to 100 m (Favorite 1974) with an average depth of 75 m and contains sand and mud bottom sediments (Smith and McConnaughey 1999; Table 3).

The RKCSA and the NBBCA have similar physical characteristics, including depth, surface and bottom temperature, bottom sediments, and location on the Bering Sea continental shelf (Table 3). A 4,000-nmi^2 area located in southern Bristol Bay south of yellowfin sole trawling activities was chosen as an experimental closed area (C1; Figure 2). The entire RKCSA was chosen as an experimental closed area (C2; Figure 2).

Two areas of similar size, depth, bottom sediments, and shelf habitat (Table 3) that have been open consistently to bottom trawling throughout history were used as controls. These areas were designated Fished Area 1 (F1) and Fished Area 2 (F2), (Figure 2; see Appendix 2 for area coordinates).

The purpose of this study was to determine if total abundance, total biomass, diversity, species evenness, abundance and biomass of dominant species, and abundance and biomass of functional feeding groups (FFGs) were greater in post-closure years in experimental closed areas when compared to controls. Prior to closure, all four areas were expected to have had similar characteristics and therefore were comparable controls. In years following the closures, 1996-2000, the experimental closed areas were expected to have greater total abundance, total biomass, diversity, and evenness, abundance and biomass of dominant species, and abundance and biomass of functional feeding groups when compared to years prior to closure in order to be deemed effective marine protected areas in the eastern Bering Sea. This also tested possible indirect effects of closed areas on community composition of species and determination of a probable recovery time for these species within closed areas in the eastern Bering Sea.

METHODS

The National Marine Fisheries Service (NMFS) conducts a bottom trawl survey in the eastern Bering Sea (EBS) May through August each year to determine the abundance and distribution of crab and groundfish resources (Stevens et al. 2000a). The survey area, which was standardized in 1990, consists of approximately 380 tows (duration ~ 30 min; length ~ 1.5 nmi) and covers an area of approximately 139,200 nmi^2 (Stevens et al. 2000a). The trawl survey is based on a 20 by 20 nmi grid (Figure 2). The survey employs two vessels, each with an Eastern otter trawl with a 25.3 m headrope and a 34.1 m footrope. The Eastern otter trawl is equipped with a small mesh liner of 3.2 cm (stretched) (Witherell and Ianelli 1997). The same vessels (*F/V Aldebaran* and *F/V Arcturus*) have been used since 1993. The survey method and use of an Eastern otter trawl was standardized in 1982 (Stevens et al. 1998). These consistent methods provide a basis for comparison among areas contained within the bottom trawl survey area.

The NMFS (Eric Brown RACE/NMFS Seattle, WA, pers.comm.) provided copies of the Bering Sea bottom trawl survey database. It included species characteristics (species presence, abundance, and weight) and haul characteristics (location, sampling date, depth, surface temperature, bottom temperature, distance traveled, and effective width of trawl). All available stations sampled by NMFS (7-15 stations/area/year) within each of the four areas were selected for each year from 1990 through 2000 (total number of stations = 427). The number of stations sampled per area per year was increased within NBBCA and RKCSA in 1999 and 2000 to determine abundance and condition of female red king crabs (Stevens et al. 2000a & b). This time frame was chosen to allow examination of catches prior to (1990-1994) and after (1996-2000) bottom trawling was prohibited by Amendment 37 in the NBBCA and the RKCSA. Data from 1995 were not analyzed because the closures occurred during the calendar year. Eliminating the data from 1995 also allowed for the same number of years, pre-closure versus post-closure, to be analyzed with contrast statistics.

For each haul, dominance was defined as any species that represented 5% or greater abundance of more than one haul over the entire data set. If abundance was not recorded, dominance was defined as any species that represented >5% weight of more than one haul. This allowed rejection of certain taxa that were present, but not dominant, or those that occurred in only one haul. Using the same methods as were used to estimate crab population size from the Bering Sea summer bottom trawl survey (Stevens et al. 2000a), a standardized catch per unit effort (CPUE) was calculated based on area swept of each haul. Area swept was determined by distance traveled (determined from vessel positions recorded by GPS at the beginning and end of each haul) multiplied by the effective width of the trawl (wingspread) given by the NMFS. Total abundance and total biomass were calculated for each haul and for all species, and were standardized by CPUE. This was done by multiplying each value for abundance and biomass, given by the NMFS, by the calculated CPUE, yielding values for abundance and biomass that were comparable among all areas and across all years. Abundance and biomass of all species in all hauls for all areas were standardized by CPUE.

Functional feeding groups (FFGs) of dominant species were determined from published literature. Each dominant species was assigned to a group of taxa that "obtain food in similar ways, regardless of taxonomic affinities" (Gevrey et al. *in press*). FFGs include piscivores, benthic invertebrate feeders, carnivores, detritivores, planktivores, filter-feeding invertebrates, and miscellaneous species. These FFGs can provide insight as to what food resources are available (Gevrey et al. *in press*) and the effect of closed areas on each functional feeding group (Murawski et al. 2000).

Within communities there are rare species and abundant species. Most species usually make up a small portion of the entire community, while many individuals of a few species make up the rest of the community (Smith 1996). Indices of diversity and evenness provide information about different characteristics of the distribution of species within a population.

The Shannon-Wiener diversity index was calculated for each of the areas and for all of the years. This index takes into account both species richness (the number of species within an area) and evenness (the relative abundance of individuals among the species) (Smith 1996). The Shannon-Wiener diversity index was calculated as:

$$H = -\sum_{i=1}^{s} (p_i)(\ln p_i)$$

Where: H = Shannon-Wiener diversity index

s = number of species

ln = natural log

p_i = the proportion of individuals of the total sample belonging to the ith species.

The Shannon-Wiener diversity index measures uncertainty. This states that the greater the value of the index (H), the greater the uncertainty. This means, that in a random sampling design, the probability is low that the next individual chosen from a group will not belong to the same species as the previously drawn individual. In contrast, when the value of diversity (H) is low, the possibility is high of choosing an individual belonging to the same species as the previously chosen individual. This index increases when the number of individuals is more equitably distributed among species within the total population (Smith 1996). Diversity indices were compared among areas and across years.

Species evenness also was determined for all areas and across years using the Shannon Index of Evenness (Smith 1996). This Evenness Index ranges from 0 to 1.0, where 1.0 is the maximum possibility of evenness. If the index is at a maximum, all species within an area occur in the same relative abundance. The Shannon Index of Evenness was calculated as:

$$J = H/H_{max} = -\sum_{i=1}^{s} (p_i \ln p_i)/\ln s$$

Where:

J = Shannon index of evenness

s = number of species

ln = natural log

p_i = the proportion of individuals of the total sample belonging to the ith species.

The Shannon Index of Evenness compares the "proportion of individuals in the community to the maximum probability of evenness" (Smith 1996). In communities with a large range of differently sized organisms, evenness indices may underestimate the importance of large, rare organisms, while overestimating abundant species (Smith 1996).

Several different indices for diversity and evenness have been used in marine science (Bell 1983; Jewett et al. 1999; Mueter and Norcross 1999). The Shannon-Wiener diversity index and the Shannon Index of Evenness were chosen based on their wide usage and their ability to provide available comparisons within communities, between communities, and between communities over a large geographical area (Whittaker 1972).

These measures are biased towards larger species within the scope of this study because both of these indices were used to take into account the abundance of particular species within a community. Not all species in this study were represented by abundance values. All data were analyzed and those species that did not have abundance values associated with them were not included in the analyses of diversity and evenness. Other types of measures of heterogeneity are recommended for evaluation of this study in order to represent all species.

The semivariograms, a standard statistical measure of spatial variability as a function of the distance between observations (Littell et al. 2002), was used to estimate the following geostatistical parameters: nugget, sill, and range for use in the SAS procedure (version 8.2) Proc Mixed model. The nugget of a semivariogram is the intercept, the sill is the value at which the semivariogram reaches a plateau, and the range is the distance value where the semivariogram reaches the sill (Littell et al. 2002). These parameters were essential in estimating the spatial correlation between latitude and longitude, and distances, of data points (Littell et al. 2002).

Total abundance, total biomass, diversity, and evenness of each haul, abundance and biomass of *Paralithodes camtschaticus*, abundance and biomass of dominant species, and abundance and biomass of functional feeding groups were compared among areas, among years, and for the interaction between area and year (area*year). The tool for these comparisons was a univariate ANOVA using spatial correlations to create a linear model that uses repeated measures to make pair-wise comparisons (SAS version 8.2, 2003) (see Appendix 3). Means were compared for significance (F values are in Appendix 4, $n=427$, $p<0.0001$). A univariate ANOVA was run to compare different combinations of pairs of areas across all years. This resulted in six combinations of pairs: C1|C2, C1|F1, C1|F2, C2|F1, C2|F2, and F1|F2. A Tukey-Kramer adjustment option was used to eliminate spatial correlation and to pinpoint where differences in these comparisons were located (see Appendix 3) (t-values are located in Appendix 4).

If the interaction term for area*year was not significantly different ($p<0.0001$), for abundance or biomass of a dominant non-target species, that species was not included in further analysis. This was done because any species that did not exhibit an interaction between area and year would be unlikely to exhibit a difference between pre-closure and post-closure years within an area. If the dominant non-target species was not found in a particular haul or year, the CPUE was set to zero.

Comparisons were made between closed and fished areas for all years to determine if overall differences occurred between areas. Comparisons of aggregates of pre-closure (1990-1994) and post-closure (1996-2000) years were made to determine if overall trends over time occurred in all four areas. Comparisons of aggregates of pre-closure and post-closure years within each area were made to determine if closure of Closed Area 1 and Closed Area 2 (C1 and C2) were significantly different in post-closure years when compared to pre-closure years and to determine if differences in time occurred within each of the fished areas. This was statistically examined with a Proc Mixed model that contained contrast statements (see Appendix 5). The contrast statements used a series of comparison values: 1, -1, and/or 0 to compare data values calculated as Differences of Least Squares Means by the Proc Mixed program. The series of Differences of Least Squares Means are copied into each contrast statement. Data values, represented by a 1, are compared to data values, represented by a -1. All other data values present in the series that were not used for that particular comparison were represented by a 0 (Littell et al.2002). These six contrasting statements combine data to determine if significant differences occurred (F values are in Appendix 6, $n=427$, $p<0.01$, $p<0.001$, $p<0.0001$). The comparisons were: 1) among closed areas and fished areas, 2) comparison of the years 1990-1994 to 1996-2000, 3) comparison of 1990-1994 to 1996-2000 in C1; 4) comparison of 1990-1994 to 1996-2000 in C2; 5) comparison of 1990-1994 to 1996-2000 in F1; and 6) comparison of 1990-1994 to 1996-2000 in F2. For statistically significant differences ($p<0.01$), distribution plots of total abundance, total biomass, diversity, and evenness, abundance and biomass of *Paralithodes camtschaticus,* dominant species, and functional feeding groups were examined to determine the direction of change (increase, decrease, or no change) for closed versus fished areas in pre-closure and post-closure years.

RESULTS

Species Characteristics

The total number of species sampled in all four areas from the years 1990 to 2000 was 228. Of these 228 species, there were 68 chordates, nine hemichordates, 23 echinoderms, 39 arthropods, five annelids, 64 mollusks, four bryozoans, one sipunculid, nine cnidarians, three sponges and three miscellaneous groups (unidentified invertebrates, empty bivalve shells, and empty gastropod shells) (see Appendix 7 for a complete list of species).

Total number of species and taxa varied among closed and fished areas for the years 1990 to 2000 (Table 3, Appendix 7). Closed Area 1 had 108 species: 36 chordates, six hemichordates, 11 echinoderms, 22 arthropods, 21 mollusks, two bryozoans, five cnidarians, two sponges, and three miscellaneous. Closed Area 2 had 101 species: 28 chordates, three hemichordates, nine echinoderms, 23 arthropods, three annelids, 24 mollusks, one bryozoan, one sipunculid, five cnidarians, three sponges, and three miscellaneous. Fished Area 1 had 144 species: 44 chordates, four hemichordates, 15 echinoderms, 26 arthropods, three annelids, 40 mollusks, one bryozoan, seven cnidarians, one sponge, and three miscellaneous. Fished Area 2 had 107 species: 37 chordates, nine hemichordates, nine echinoderms, 18 arthropods, two annelids, 21 mollusks, two bryozoans, six cnidarians, one sponge, and two miscellaneous. Although numbers of species were different among areas, each area was made up of similar species encompassed in other areas.

Of the total of 228 species collected, 29 were designated as dominant species for abundance (Table 4). Of these dominant species there were nine chordates, one echinoderm, five arthropods, 13 mollusks, and one cnidarian. Forty-seven species were designated as dominant species for biomass (Table 5). Of these dominant species there were nine chordates, four hemichordates, eight echinoderms, eight arthropods, 14 mollusks, two cnidarians, one sponge, and one miscellaneous. All species that were significantly different for biomass among areas, among years, and for the interaction of area*year were also statistical significant for abundance, if abundance was collected.

The dominant species were divided into six functional feeding groups (FFGs) and one miscellaneous category (Table 6). These groups were piscivores, benthic invertebrate feeders, carnivores, detritivores, planktivores, and filter-feeding invertebrates (Gevrey et al. *in press*). The piscivores include fish species that eat other fish (Hart 1973; Cohen et al. 1990). The benthic invertebrate feeders are fish species that eat benthic invertebrates (i.e. crustaceans, worms, brittlestars) (Clemens and Wilby 1961; Hart 1973; Zhang 1988). The carnivores are large crab and starfish species that scavenge for small mollusks and worms (Hyman 1955; Feder and Jewett 1981; O'Clair and O'Clair 1998). The detritivores are small crabs and whelks that eat detritus and bacteria (O'Clair and O'Clair 1998). The planktivores are jellyfish that feed on plankton in the water column (Kozloff 1996; Suchman and Sullivan 1998). The filter-feeding invertebrate group contains tunicates and sponges that feed by filtering organisms from nutrient-rich sea water (Bingham and Walters 1989; O'Clair and O'Clair 1998; Ribes et al. 1998). The miscellaneous category is empty gastropod shells.

Total Characteristics

Total abundance, total biomass, diversity and evenness were compared among areas and years (Figure 3, Table 7, see Appendix 8 for original values). Total abundance and biomass were not significantly different among the four areas combined. The diversity indices were significantly different among areas ($p<0.0001$), but evenness was not. Total biomass of all areas combined was significantly different among years ($p<0.0001$) but total abundance, diversity and evenness were not. Total abundance, diversity, and evenness were significantly different for the interaction of area*year (Table 7). When areas were compared in combinations of pairs, no significant differences were found for total biomass or total abundance. Diversity and evenness were significantly different in Fished Area 1 when compared to both closed areas (Table 7).

Total abundance, biomass, diversity, and evenness yielded few significant differences when compared between closed areas and fished areas or between pre-closure and post-closure years, although some differences within specific areas occurred (Table 8). Total abundance and biomass exhibited no significant change between closed areas and fished areas, between years prior to and after closure, or between years prior to and after closure within each area. Diversity was significantly greater in fished areas than in closed areas and significantly greater in post-closure years than in pre-closure years. Diversity was significantly greater in post-closure years in Fished Area 1. Evenness was greater in fished areas than in closed areas but no significant differences were found between pre-closure and post-closure years or between years within areas.

Paralithodes camtschaticus –Red King Crab

The abundance and biomass of *Paralithodes camtschaticus* was compared among areas and among years (Figure 4). The total abundance of *P. camtschaticus* was significantly different among areas but not among years and the interaction between area and year (Table 9). Comparisons of combinations of areas yielded significant differences between closed areas and fished areas but no difference within closed and fished areas (Table 9). The total biomass of *P. camtschaticus* was significantly different for area but exhibited no significance for year or the interaction between area and year (Table 9). Comparisons of combinations of areas yielded similar results to those of abundance. Closed areas and fished areas were significantly different but there was no difference within closed and fished areas (Table 9).

Paralithodes camtschaticus was significantly greater in closed areas for abundance and biomass (Table 10). Abundance was greater in post-closure years within Closed Area 1 and Closed Area 2. Biomass was significantly greater in closed areas when compared to fished areas and in post-closure years within Closed Area 2.

Dominant Species Abundance

The total abundance of several dominant species was significantly different among areas (Table 11, see Appendix 9 for graphs). Of the 29 species considered dominant (abundance), two arthropods and five mollusks were significantly different among areas. Fifteen species were significantly different in abundance for year (Table 11): four chordates, four arthropods, six mollusks, and one cnidarian. Fourteen species were significantly different in abundance for the interaction between area and year (Table 11): three chordates, three arthropods, and eight mollusks.

There were few significant differences in abundance between pairs of areas between 1990 and 2000 (Table 11). Of a possible 174 (six comparisons for 29 species), only 14 pairs yielded significant differences. Comparisons between the two closed areas, C1|C2, yielded no significant differences. Comparisons between the two fished areas, F1|F2, resulted in significantly different abundance of one arthropod. Examination of individual closed and fished areas showed some similarities and some differences for combinations. Comparisons for C1|F1 yielded significantly different abundances in one arthropod and two mollusks. Comparisons for C1|F2 yielded significantly different abundance of two arthropods and one mollusk. Comparisons for C2|F1 yielded significantly different abundances of one arthropod and three mollusks. Comparisons for C2|F2 yielded significantly different abundances of two arthropods and one mollusk.

Several species were significantly different in abundance for many combinations of areas (Table 11). *Chionoecetes bairdi* was significantly different for Fished Area 2 when compared to all other areas. *Chionoecetes opilio* was significantly different between closed and fished areas. Unidentified *Buccinum* was significantly different for Fished Area 2 when compared to both closed areas. *Buccinum angulosum* and *Buccinum scalariforme* were significantly different for Fished Area 1 when compared to both closed areas.

Several dominant species showed differences in abundance between closed areas and fished areas, between pre-closure and post-closure years, and between years within each area (Table 12). Only one species exhibited greater abundance in closed areas, while eight species were greater in fished areas. Five species were greater in abundance in years 1990-1994 while four were greater in years 1996-2000. Ten species were greater in pre-closure years within areas while 12 species were greater in post-closure years within areas.

Chionoecetes bairdi were greater in abundance in closed areas when compared to fished areas but decreased over time in all areas (Table 12). One species of arthropod and seven species of mollusk were greater in fished areas when compared to closed areas. These species differ taxonomically and by functional feeding group but most are either small in size or large and robust. A similar number of species were greater in pre-closure years as were greater in post-closure years (Table 12). The five species that were greater in pre-closure years were *Atheresthes stomias, Theragra chalcogramma, Hyas spp, Chionoecetes bairdi,* and *Chionoecetes opilio.* The four species that were greater in post-closure years were *Pagurus aleuticus, Buccinum spp, Neptunea heros,* and *Volutopsius fragilis.*

Two chordates, two arthropods, and two mollusks yielded greater abundance in pre-closure years within specific areas (Table 12). Two chordates, two arthropods and four mollusks were greater in post-closure years within specific areas. Fourteen of the possible 16 species that were significantly different in pre-closure or post-closure years within specific areas either increased or decreased in some or all areas. Of these 14, only four species (three chordates and one arthropod) were significantly different solely in closed areas. Eight species (one chordate, one arthropod, and six mollusks) were different in fished areas. The remaining two arthropod species were significantly different in some closed and some fished areas.

Two species that were significantly different in abundance in pre-closure or post-closure years within specific areas yielded a combination of results (Table 12). *Chionoecetes bairdi* decreased in both closed areas and Fished Area 2. *Pagurus aleuticus* increased in both closed areas and Fished Area 1. These species differ taxonomically and by functional feeding group; *C. bairdi* is large in size and *P.* aleuticus is fragile and small.

Dominant Species Biomass

The total biomass of several dominant species was significantly different among areas (Table 13, see Appendix 9 for graphs). Of the 47 species considered dominant (biomass) one chordate, one hemichordate, four echinoderms, two arthropods, and one mollusk were significantly different among areas. Twenty-eight species were significantly different in biomass among different years (Table 13): six chordates, three hemichordates, three echinoderms, six arthropods, seven mollusks, two cnidarians, and empty gastropod shells. Twenty-five species were significantly different for biomass for the interaction of area*year (Table 13): four chordates, one hemichordate, three echinoderms, six arthropods, nine mollusks, one cnidarian, and empty gastropod shells. There were few significant differences in biomass between pairs of areas (Table 13). Of a possible 282 pairs (six comparisons for 47 species), only 22 pairs yielded significant differences. Comparisons between the two closed areas, C1|C2, yielded no significant differences. Comparisons between the two fished areas, F1|F2, resulted in significantly different biomass of one chordate, three echinoderms, and one arthropod. Examination of individual closed and fished areas showed some similarities and some differences for combinations. Comparisons for C1|F1 yielded significantly different biomass of three echinoderms, one arthropod, and one mollusk. Comparisons for C1|F2 yielded significantly different biomass of one chordate and two arthropods. Comparisons for C2|F1 yielded significantly different biomass of four echinoderms, one arthropod and one mollusk. Comparisons for C2|F2 yielded significantly different biomass of one chordate and two arthropods.

Several species were significantly different in biomass for many combinations of areas (Table 13). *Hippoglossoides elassodon* and *Chionoecetes bairdi* were significantly different for biomass in Fished Area 2 when compared to all other areas. *Leptasterias polaris*, unidentified ophiuroids, and *Ophiura sarsi* were significantly different for biomass in Fished Area 1 when compared to all other areas. *Chionoecetes opilio* were significantly different for biomass in closed areas when compared to fished areas. Unidentified *Buccinum spp.* were significantly different in biomass for Fished Area 2 when compared to both closed areas and *Buccinum scalariforme* was significantly different for biomass for Fished Area 1 when compared to both closed areas.

Several dominant species showed differences in biomass between closed areas and fished areas, between pre-closure and post-closure years, and between years within each area (Table 14). One species of chordate, one arthropod, and one cnidarian were greater in closed areas when compared to fished areas. One species of hemichordate, three species of echinoderm, two species of arthropod, and seven species of mollusk were greater in fished areas than closed areas. A similar number of species were greater in pre-closure years as were greater in post-closure years (Table 14). The eight species that were greater in pre-closure years were *Atheresthes stomias,* ascidian *spp,* unidentified sea stars, *Leptasterias polaris, Hyas spp, Chionoecetes bairdi, C. opilio,* and unidentified gastropods. The 10 species that were greater in post-closure years were *Halocynthia spp, Styela rustica, Leptasterias arctica, Ophiura sarsi, Pagurus spp, Pagurus aleuticus, Buccinum spp, Neptunea heros, Volutopsius fragilis, and* empty gastropod shells.

Two chordates, two hemichordates, three echinoderms, two arthropods, and two mollusks yielded significantly greater biomass in pre-closure years within specific areas (Table 14). One chordate, two hemichordates, two echinoderms, two arthropods, four mollusks, one cnidarian and empty gastropod shells were greater in biomass in post-closure years within specific areas. Twenty-five of the possible 30 species that were significantly different in pre-closure or post-closure years within specific areas either increased or decreased in some or all areas. Of these 25, only three species (two chordates and one hemichordate) were significantly different solely in closed areas. Fifteen species (one chordate, three hemichordates, four echinoderms, one arthropod, five mollusks, and one cnidarian) were significantly different in fished areas. The remaining seven species (one chordate, one echinoderm, four arthropods, and empty gastropod shells) were significantly different in some closed and some fished areas.

Seven species that were significantly different for biomass in pre-closure or post-closure years within specific areas did not all increase in abundance and biomass (Table 14). *Mallotus villosus* increased in C1 but decreased in F2. *Asterias amurensis* decreased in C1 and both fished areas. *Pagurus spp* increased in C2 and F2. *Chionoecetes bairdi* biomass decreased in all four areas while *Chionoecetes opilio* increased in both closed areas but decreased in F2. *Pagurus aleuticus* increased in both closed areas and F1. Empty gastropod shells increased in C1 and in both fished areas.

Functional Feeding Groups

The abundance and biomass of functional feeding groups (FFGs) were compared among areas and among years (Figure 5). Piscivores were the only functional feeding group to exhibit significantly different abundance among years and the interaction of area*year (Table 15). No combinations of areas were significant for abundance.

Abundance data were available for only 2 functional groups (Table 16). The abundance of piscivores was not significantly different between closed and fished areas but was significantly greater in post-closure years when compared to pre-closure years. These differences were coupled with a decrease in abundance in post-closure years within both fished areas. Benthic invertebrate feeders were not significantly different among areas, among years, or among years within specific areas.

Several functional feeding groups exhibited significantly different biomass among areas, among years, and for the interaction of area*year (Table 17). The filter-feeding invertebrate group was significantly different for biomass among areas. The piscivores, carnivores, and planktivores were significantly different for biomass among years. The piscivores, benthic invertebrate feeders, planktivores, and filter-feeding invertebrates were significantly different in biomass for the interaction of area*year.

One comparison of functional groups between pairs of areas yielded significantly different biomass (Table 17) out of a possible 36. Filter-feeding invertebrates were significantly different in biomass in C1:C2.

Several functional groups exhibited significant differences in biomass between closed areas and fished areas, between pre-closure and post-closure years, and between years within each area (Table 18). Biomass of detritivores was greater in fished areas and biomass of planktivores was greater in closed areas. Other groups were not significantly different between closed and fished areas at all. Carnivores were greater in biomass in pre-closure years when compared to post-closure years. Estimates of biomass of two functional feeding groups were greater prior to closure within some areas and two others were greater in post-closure years within areas. Benthic invertebrate feeders were greater in biomass in post-closure years in Closed Area 1. Filter-feeding invertebrates exhibited a combination of results with greater biomass in pre-closure years within C1 but a greater biomass in post-closure years in F2. There were no significant changes over time within Closed Area 2.

DISCUSSION

Bottom trawling can have adverse effects on fish communities. The direct effects of bottom trawling include modification of substrate (Brylinsky et al. 1994; Auster et al. 1996; McConnaughey et al. 2000; Smith et al. 2000; NRC 2002), disturbance of benthic communities (Collie et al. 2000a, 2000b; Jennings et al. 2001a; NRC 2002), and removal of target and non-target species (Garrison 2001; NRC 2002). These effects reduce habitat complexity (Auster et al. 1996; Engel and Kvitek 1998; Collie et al. 2000b; NRC 2002) decrease species richness, diversity and evenness (Engel and Kvitek 1998; NRC 2002), and create a shift in community composition from large species to small opportunistic species (Engel and Kvitek 1998; Simboura et al. 1998; Freese et al. 1999; Collie et al. 2000a; McConnaughey et al. 2000; Smith et al. 2000; Jennings et al. 2001a, 2001b; NRC 2002).

Total Characteristics

This study of areas closed to bottom trawling in the eastern Bering Sea and areas that allow bottom trawling to occur provides support that direct and indirect effects of bottom trawling occur in the eastern Bering Sea. Although total biomass and abundance did not change, Fished Area 1 had a greater number of species, a greater number of dominant species and a greater diversity of species in post-closure years when compared to pre-closure years (Tables 3 & 8). The increase in diversity in a fished area contradicts other findings that diversity increases in areas closed to fishing (Schmidt 1997; Roberts 1998; NPFMC 2003). The increase in diversity in fished areas in the eastern Bering Sea supports a possible change in community composition of species.

Evenness was greater in fished areas when compared to closed areas, although significance was low ($p<0.01$) (Table 8). However, evenness was not significantly different between pre-closure and post-closure years. The failure to detect differences in evenness over time may be due to similar habitat characteristics such as depth and sediment type. Evenness may also be affected by patchiness in habitats. Ecological experiments in the wild may evaluate habitats that are not identical (Roberts and Polunin 1992), thus creating constraints in evaluating the effects of closed areas by making it hard to distinguish effects resulting from the protection afforded by marine protected areas from variation in habitat (Garcia-Charton and Perez-Ruzafa 1999; Paddack and Estes 2000).

Dominant Species Characteristics

Many studies have provided information supporting the conclusion that areas closed to fishing can effectively increase abundance, biomass, diversity and evenness of target and non-target species. Data represented here (Table 10) coupled with annual surveys of the eastern Bering Sea have shown that abundance and biomass of the target species, *Paralithodes camtschaticus,* increased in closed areas (Stevens et al. 1998; Stevens et al. 2000a, 2000b). This study also provided data that some non-target species increased in closed areas (Tables 12 & 14).

In Georges Banks, fishing closures have led to effective conservation of target (e.g. Atlantic cod; *Gadus morhua*) and non-target (e.g. sea scallops; *Placopecten magellanicus*) species (Murawski et al. 2000). Several studies have shown an increase in target species abundance (Roberts and Polunin 1992; Polunin and Roberts 1993; Roberts 1995), density of fish species (Paddack and Estes 2000), and target species biomass (Roberts and Polunin 1992; Polunin and Roberts 1993; Roberts 1995) within closed areas. One study tested the reverse effect by opening a closed area to fishing and abundance subsequently decreased in reef fish (Alcala and Russ 1990).

Trawling can affect communities directly by removal of large predators that facilitate decreased predation on smaller species (Jennings et al. 2001a). Several predatory fish species and crab species have decreased in the late 1990's in the eastern Bering Sea (NPFMC 2001). These include *Mallotus villosus* (capelin), sculpins, sablefish, poachers, *Chionoecetes bairdi* (Tanner crab), and *C. opilio* (narrow snow crab) (NPFMC 1999; NPFMC 2001). This study presented data that *Theragra chalcogramma, Mallotus* *villosus, Chionoecetes bairdi* and *C. opilio*, all large predators, decreased in fished areas over time. This could have an overall effect on community characteristics.

Several studies on bottom trawling have provided data for a possible shift in community characteristics from those dominated by high biomass species to high abundance of low biomass species (Messieh et al. 1991; Prena et al. 1999; Collie et al. 2000a; NRC 2002). Although not definitive, changes in community composition support the idea that some large-bodied fish decrease in areas where bottom trawling occurs and are replaced by numerous, small, opportunistic scavenger species. Scavenging sea stars increased throughout the eastern Bering Sea in the 1990's (NPFMC 1999). Data presented here demonstrate that small mollusks are greater in abundance and biomass in fished areas and increase in fished areas over time (Tables 12 & 14). Several sea stars are also greater in biomass in fished areas (Table 14).

Functional Feeding Group Characteristics

Piscivores were greater in abundance in pre-closure years in fished areas when compared to post-closure years (Table 16). A decrease in piscivore abundance and biomass in 1999 in all areas, followed by an increase in 2000, may be a result of record-cold temperatures in 1999 followed by conditions closer to normal in 2000, particularly in the middle shelf region (NPFMC 2003). The middle shelf, where these study areas are found, contains a cool pool of water, in its subsurface layers, which is related to sea ice, bathymetry, air temperatures, and currents (Wyllie-Echeverria and Wooster 1998). This cool pool, variations in sea ice, and cold temperatures may affect behavior and distribution of some fish species sensitive to cooler temperatures (Wyllie-Echeverria and Wooster 1998; Hollowed et al. 2001; NPFMC 2003). This change in distribution can provide information about climate effects on ecosystems.

Carnivores were greater in pre-closure years when compared to post-closure years and decreased significantly in Closed Area 1 but exhibited no significant difference in any other area (Table 18). The absence of bottom trawling could have decreased prey in Closed Area 1. Some direct effects of bottom trawling on organisms include reduction of fish by catch and mortality due to contact with trawl gear (Kaiser and Spencer 1996). Although some organisms that contact trawl gear die, others are merely injured, thus attracting carnivorous scavengers and indirectly affecting community composition (Kaiser and Spencer 1996; Ramsay et al. 1998; Prena et al. 1999; Smith et al. 2000; Jennings et al. 2001a). The recovery rate of opportunistic species (r-selected species) in less stable environments can be rapid (Collie et al. 2000a). The magnitude of response can also vary among habitats and among different species, allowing for inconsistent responses at different locations (Ramsay et al. 1998).

Detritivores were greater in biomass in fished areas when compared to closed areas while planktivores were greater in biomass in closed areas (Table 18). An increase in detritivores in areas where bottom trawling occurs provides evidence that bottom trawling affects communities indirectly (Jennings et. al 2001a). Bottom trawling provides an increased contact with prey, reduced competition, or predation on more productive species (Jennings et. al 2001a). Detritivores tend to have small body size and therefore exhibit high natural mortality rates, fast growth, and an increased annual reproductive output (Smith 1996). They also have greater production to biomass (P:B) ratios and may be more productive, therefore contributing to the retention of stable levels of production in a habitat despite the loss of production from larger species taken by trawling (Jennings et al. 2001a).

Bottom trawling affects habitat complexity (Collie et al. 2000a; McConnaughey et al. 2000; NRC 2002,). According to NRC (2002), soft-bodied, stalked, sessile species are more vulnerable to bottom trawling than hard-bodied, prone, species. In this study, large, robust tunicates were greater in biomass in post-closure years within some fished areas. *Styela rustica,* a robust sea potato, was also greater in fished areas when compared to closed areas. These data support the idea that large tunicates may be less vulnerable to trawling.

Marine Protected Area Implementation

Marine protected areas have been shown to be effective management tools by reducing exploitation rates and increasing spawning stock biomass in Georges Bank (Murawski et al. 2000) protecting spawning stock biomass and supplying recruits to fished areas in the Red Sea (Roberts and Polunin 1992), enhancing species diversity in California (Paddack and Estes 2000), and increasing abundance and biomass of commercially important species in the Caribbean (Polunin and Roberts 1993; Roberts 1995). This tool is most effective when considered as one approach, in combination with traditional management practices, such as quotas and seasons (NRC 2001).

Potential recovery time for a species assemblage or habitat may also play a large part in the response of areas closed to fishing perturbations. Any long-term recolonization depends on many things: the stability of an area (Jennings et al. 2001b), interannual and interdecadal climatic changes (Conners et al. 2002), tolerance of specific organisms to perturbations (Collie et al. 2000a), and availability of recruitment in all areas (Carr and Reed 1993). A few studies have suggested ample recovery times in order to assess the efficacy and design of closures. Dugan and Davis (1993) suggested 10-15 years of closure and Lauck et al. (1998) suggested 40 years.

Many studies have shown that short time periods are not sufficient in determining if closures are working. In southern California, Schroeter et al. (1993) determined that a 2-3 year period before and after a closure was not long enough to create significant changes. In Denmark, Hoffmann and Dolmer (2000) concluded that an area previously dredged for mussels exhibited no change after nine years. Three years was not sufficient enough to increase fishing levels to those prior to closure in Kenya, although CPUE increased (McClanahan and Kaunda-Arara 1996). In the North Sea, closures resulted in decreased yields and spawning stock biomass after nine years (Pastoors et al. 2000). In Norton Sound, northeastern Bering Sea, Jewett et al. (1999) found that a once-mined area had not recovered physically after five years. This study in the eastern Bering Sea analyzed the effects of bottom trawling in areas that had been closed for only five years. Based on data provided here, I conclude that this short time period was not long enough to determine the efficacy of these closures.

Size of closure has been debated in the optimal design of marine protected areas. Several models and field experiments have determined the optimal design of marine protected areas. Hastings and Botsford (1999) developed a model that determined that the size of protected coast needed to be smaller than the fished area of optimal yield, as long as traditional management practices were also established. Nowlis and Roberts (1999) created a model that determined no-take marine reserves needed to encompass 40% or more of protected areas in order to influence populations. Although small closures were concluded to have a larger edge compared to closure areas and therefore could increase spillover effects into adjacent fisheries, McClanahan and Kaunda-Arara (1996) determined that closures should make up 60% of fishing grounds. Current closed areas in the eastern Bering Sea make up 25% of the continental shelf used for fishing (Witherell et al. 2000). I conclude that a network of year-round closures incorporating 20% of fishing grounds that encompass essential fish habitat needs to be implemented in the eastern Bering Sea.

When bottom trawling is prohibited, closed areas can act as refuges from bottom perturbation for many species of fish and invertebrates (NRC 2002) and therefore are appropriate to test the effectiveness of marine protected areas or fishery exclusion zones existing in the eastern Bering Sea. This study assessed biological changes in areas historically closed to fishing to determine if areas closed to trawling have a greater quantity, diversity, and evenness of species than areas that allow trawling to occur. Although not many species in this study increased in abundance and biomass, these results indicate that closed areas within the NBBCA (C1) and the RKCSA (C2) exhibit some qualities of a working marine protected area by increasing abundance and biomass of target and some non-target species.

Recommendations

The lack of clear conclusions in this study is attributed to several factors. The diversity and evenness indices were biased in determination of haul characteristics of species. Many species in this study were characterized by biomass, not abundance. In this study, these indices were calculated based on abundance. Therefore, calculation of diversity and evenness favored larger, numerically abundant species. Other factors contributing to mixed conclusions are attributed to the extensive closure of the eastern Bering Sea throughout recent history. Although Amendment 37 of the NPFMC designated permanent, year-round closure to the Nearshore Bristol Bay Closure Area and the Bristol Bay Red King Crab Savings Area in 1995, these locations were intermittently closed due to fishing pressures and to protect various life-stages of crab and fish throughout recent history. The limited time series of data in this study also contributed to lack of concise conclusions. The 11 year time period presented in this study contained only five years of post-closure data and should be extended to include a greater number of years. Another possible design problem relates to use of bottom trawling as a source of information to determine the effects of bottom trawling. The NMFS summer bottom trawl survey database was the most extensive and standard method of data available for this study. Future studies need to incorporate less destructive forms of fishery assessment in order to determine changes in species characteristics in closed areas and the efficacy of these closures in the eastern Bering Sea.

When marine protected areas are implemented, assessment is needed to determine their effectiveness. The effectiveness of fisheries management tools needs to be assessed and discrepancies resolved in order to provide "...a stronger link between ecosystem research and fisheries management" (Livingston et al. 1993). Effective marine reserves require integration of monitoring programs with research programs to evaluate performance (NRC 2001). Monitoring programs provide important information required to effectively evaluate changes in different habitats that occur because of marine protected area implementation (Carr and Reed 1993; NRC 2001). Evaluations derived from monitoring programs can help determine effectiveness and improve design of MPAs and provide progress reports about MPAs. Research programs instigated in MPAs create opportunities for conducting experiments on spatial and temporal scales and testing hypotheses in marine ecology that focus on life histories of species (NRC 2001). These experiments can contribute valuable information needed in determining different designs of MPAs.

A more extensive study, utilizing greater than 11 years of trawl survey data and greater than five years of data following area closures is suggested for future research of closed areas in the eastern Bering Sea. Although some short-lived species can recover quickly after trawl disturbance (Collie et al. 2000b) many longer-lived species can be adversely affected and require longer periods to rebound. It is difficult to know the time required for significant changes to occur between closed and fished areas. Long-term monitoring of closures may be required from 10-15 years (Dugan and Davis 1993) to 40 years (Lauck et al. 1998) for significant effects on species characteristics to occur on a large scale. Permanent closures have been suggested to have advantages of protecting species and habitat from direct and indirect effects of fishing (Guenette et al. 1998).

Future marine protected area research in the eastern Bering Sea needs to encompass many things. Designation of marine protected areas needs to take into account extensive evaluation of existing closed areas, life-history information on multiple species, habitat information on potential sites for selection, climatic variations in the ecosystem, fishing pressure in the ecosystem, and public opinion. Designation needs to involve clear objectives including time frame, area size, comparable fished areas, vulnerable stocks or habitat, baseline information, economics, and enforcement. An experimental approach to fisheries management is important in order to be successful. Extensive research and monitoring programs need to be implemented to determine efficacy of future closures.

My recommendations for future closed areas (marine protected areas) in the eastern Bering Sea are clear. A network of closures incorporating 20% of fishing grounds that encompass essential fish habitat needs to be closed at all times. A Before-After-Control-Impact (BACI) study design (Schroeter et al. 1993) should be incorporated into the design in order to provide reference sites similar to closed sites for assessment. Coupled with traditional management practices in outer-lying, fished areas, this extensive network of closures can provide a safeguard for species and habitat against the perturbations of fishing activity and create a reserve of marine ecosystems for future generations (Ault et al. 1998; Brailovskaya 1998; Vanderklift et al. 1998). These closures should be permanent to protect sensitive habitats (Rieser 2000) and formulated with clear, concise, objectives and extensive design. "Improperly designed refuges can endanger a fishery by providing a false sense of protection (Carr and Reed 1993)". I recommend that extensive research and continued monitoring programs are key parts of the objectives of any future marine protected area established in the eastern Bering Sea. Without research and monitoring as key objectives in marine protected area implementation, it is difficult to assess adequately the effectiveness of areas closed to bottom trawling in the eastern Bering Sea. Research and monitoring programs need to incorporate all aspects of the ecosystem within closed areas. Habitat features, abundance, biomass, richness, diversity, and evenness of species, life-history information of species, climatic information, and water and sediment quality need to be assessed.

Depending on habitat features, many different techniques can be used to determine efficacy of these closures. In shallow waters, divers can be used for sediment capture (Jewett et al. 1999), invertebrate sampling via a diver-operated suction sampler (Jewett et al. 1999), photographed quadrats (Foster et al. 1991; Meese and Tomich 1992), and random point quadrats (Foster et al. 1991; Leonard and Clark 1993), and fish sampling using visual census (Bell 1983; Parker et al. 1994; McClanahan and Kaunda-Arara 1996; Ault et al. 1998; Hoffmann and Dolmer 2000). Fish assessments may utilize mark-release-resighting (MRR) techniques for underwater visual census (Zeller and Russ 2000). In deeper water, side-scan sonar is a useful tool to determine surface topography (Jewett et al. 1999; Prena et al. 1999) as well as fish numbers (Kaiser and Spencer 1994). Remotely operated vehicles can be equipped with video cameras in order to assess distribution of species (Auster et al. 1991). In fished areas acoustic surveys can be coupled with biological information gathered by existing trawls (Godo et al. 1998).

In conclusion, the NMFS annual bottom trawl survey is an effective, available monitoring program for current closed area research in the eastern Bering Sea. It has been determined that management measures adopted by the North Pacific Fisheries Management Council to close the Nearshore Bristol Bay Closure Area and the Bristol Bay Red King Crab Savings Area are effective in protecting and enhancing red king crab stocks (Stevens et al. 2000a) as well as a few non-target species as demonstrated here. These results support the need for extensive design, research, further monitoring, and a longer closure period to determine if marine protected areas are an effective tool to manage species that are not targeted by commercial fisheries in the eastern Bering Sea.

FIGURES

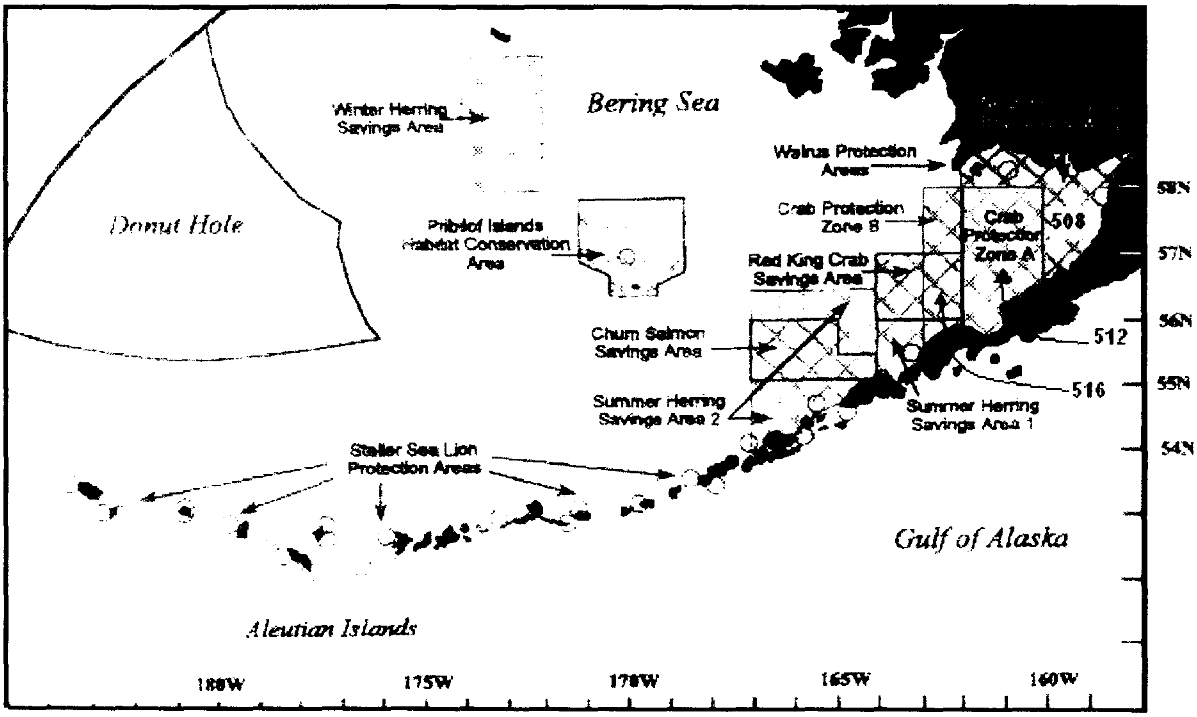
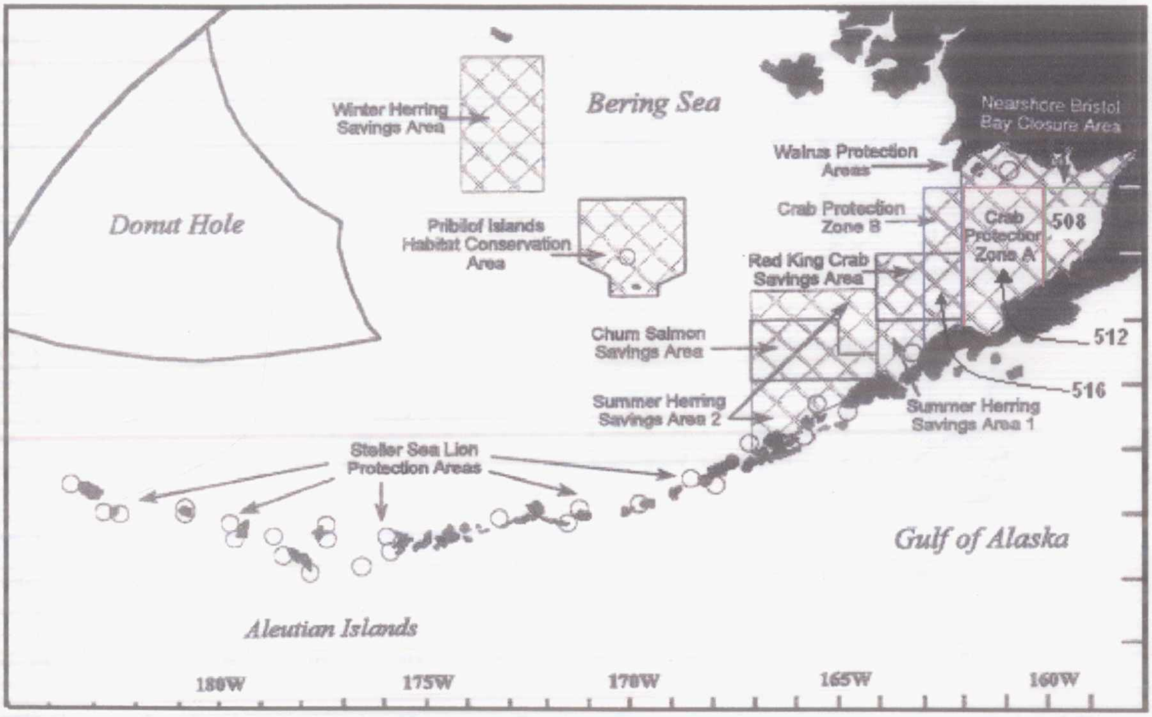


Figure 1: Bering Sea Species Protection Areas and Applicable Reporting and Regulatory Areas. Current existing closed areas in the Bering Sea and around the Aleutian Islands are shown, with the central Bering Sea donut hole for reference (Adapted from NPFMC 1997). Three reporting and regulatory areas of the Bering Sea and Aleutian Islands (BSAI) (NPFMC 1997) are shown below: area 508 (depicted in green), area 512 (depicted in red) and area 516 (depicted in blue). These areas are used to describe specific areas in the history of closed areas in the eastern Bering Sea for small-scale management of fisheries (see Table 2).

FIGURES



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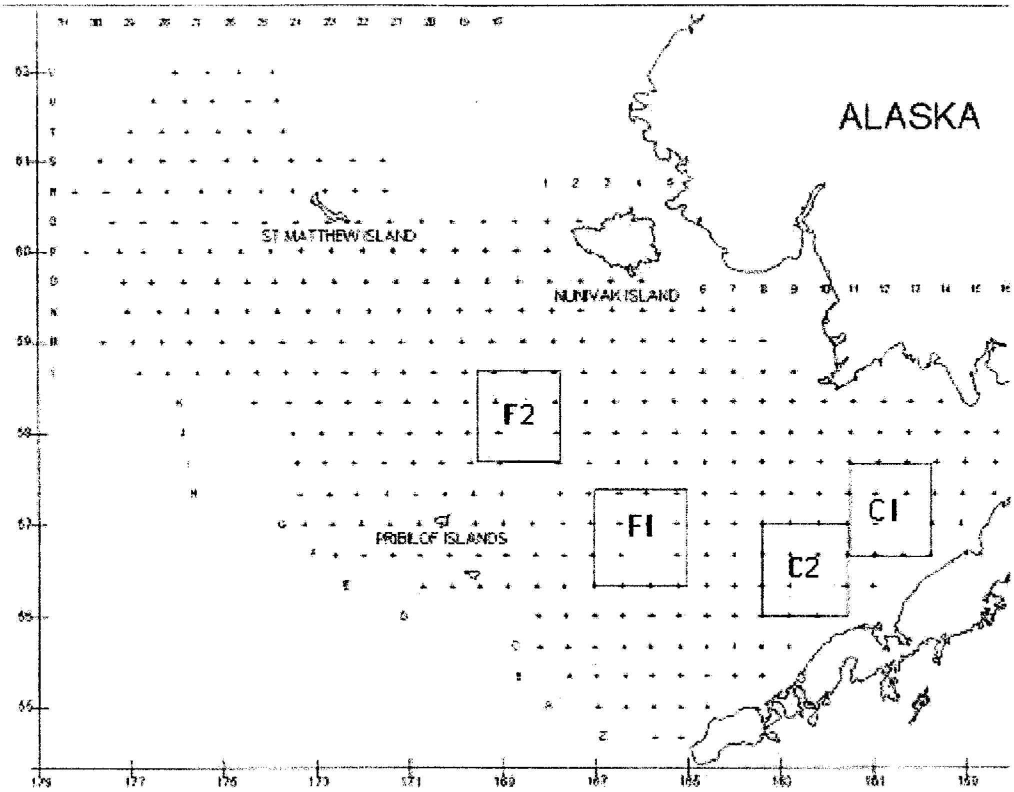
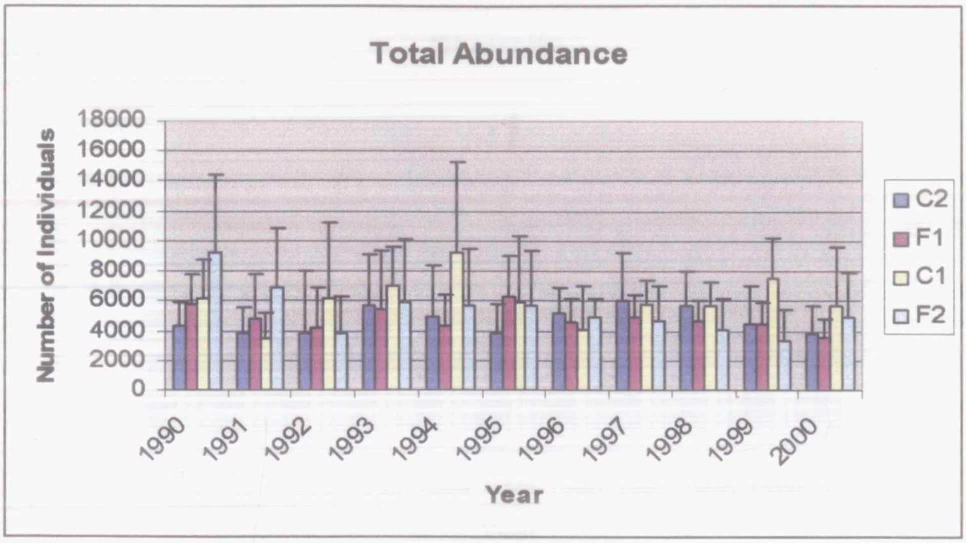


Figure 2: Study Areas in the Eastern Bering Sea. Study areas Nearshore Bristol Bay Closure Area - C1 (Closed Area 1), Bristol Bay Red King Crab Savings Area - C2 (Closed Area 2), F1 (Fished Area 1), and F2 (Fished Area 2) are superimposed on the survey area standardized by the National Marine Fisheries Service for the eastern Bering Sea trawl survey (Stevens et al. 2000a).



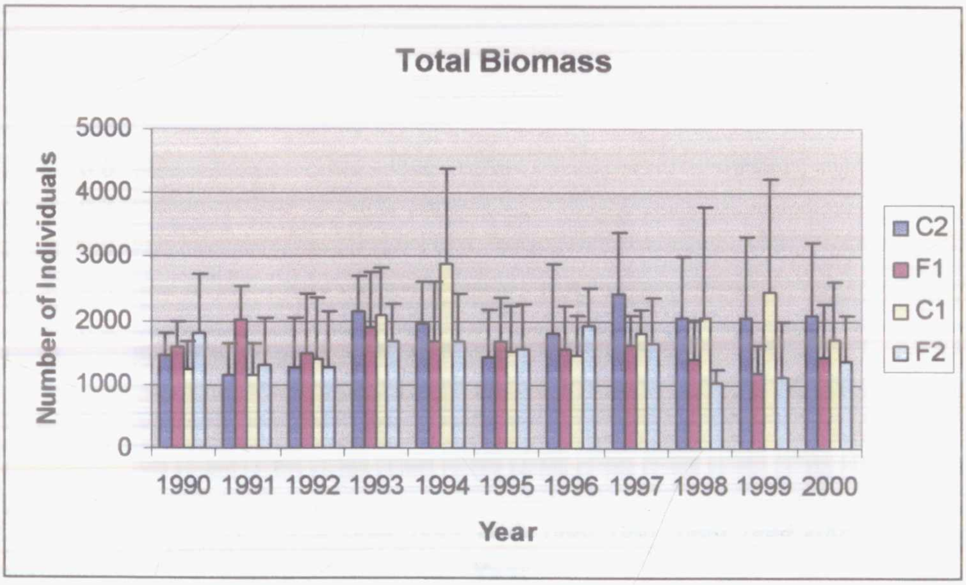
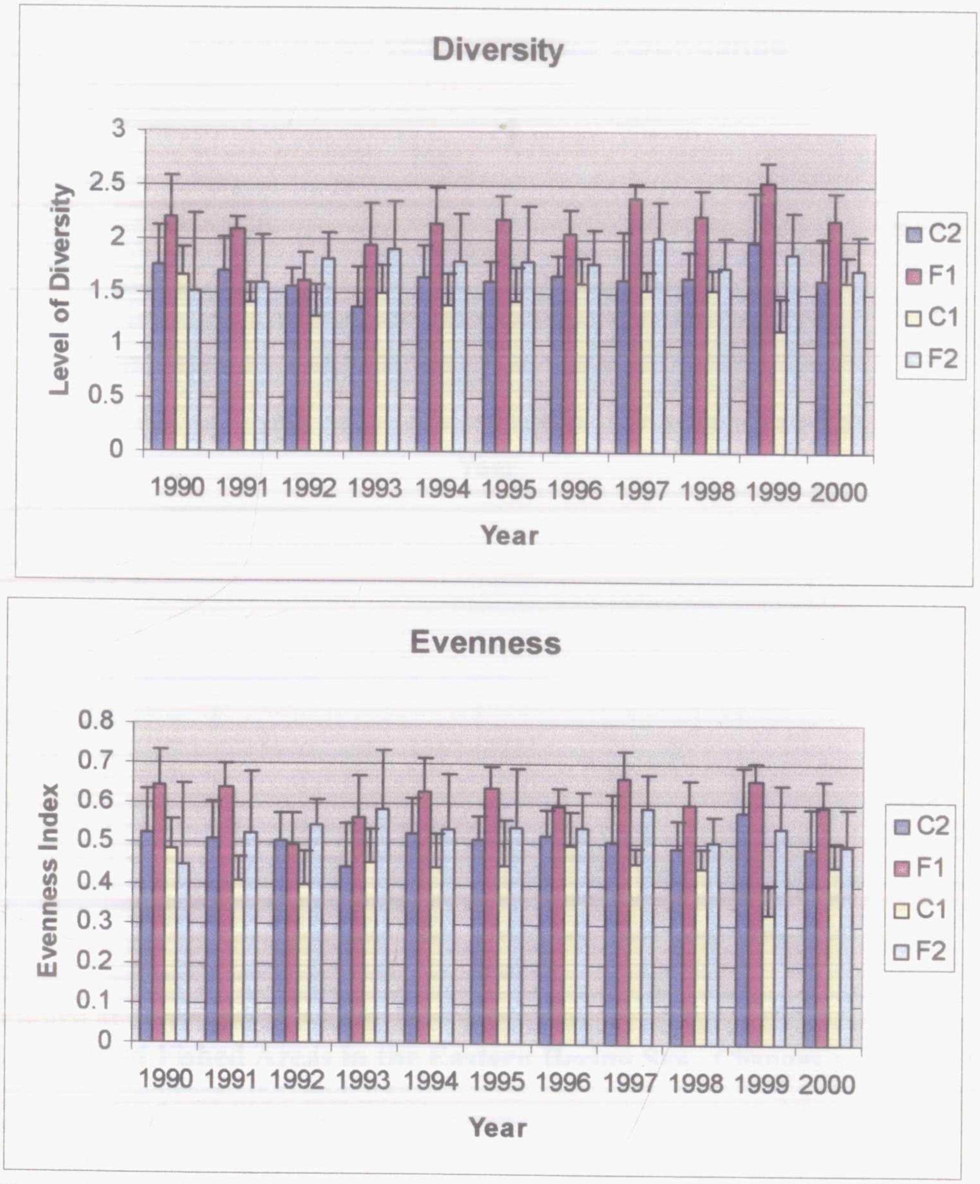


Figure 3: Average Total Abundance, Total Biomass, Diversity, and Evenness for Closed and Fished Areas in the Eastern Bering Sea. Changes between the years 1990 and 2000 are depicted below for C2 (Closed Area 2), F1 (Fished Area 1), C1 (Closed Area 1), and F2 (Fished area 2).



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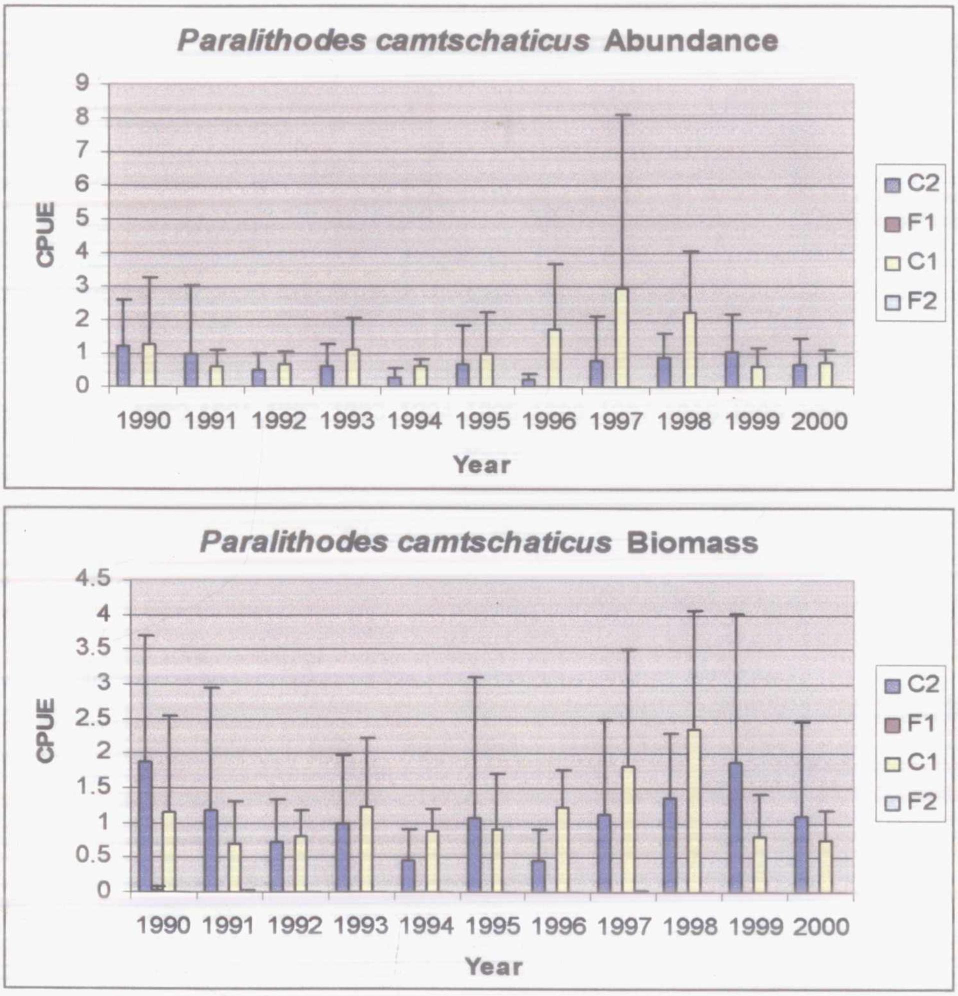
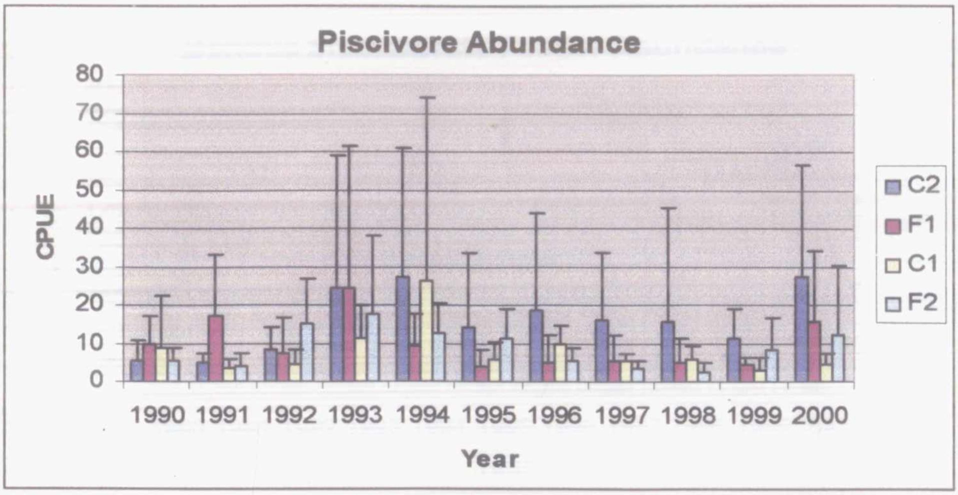


Figure 4: Averages of Abundance and Biomass of *Paralithodes camtschaticus* for Closed and Fished Areas in the Eastern Bering Sea. Changes are shown for each area between the years 1990 and 2000.



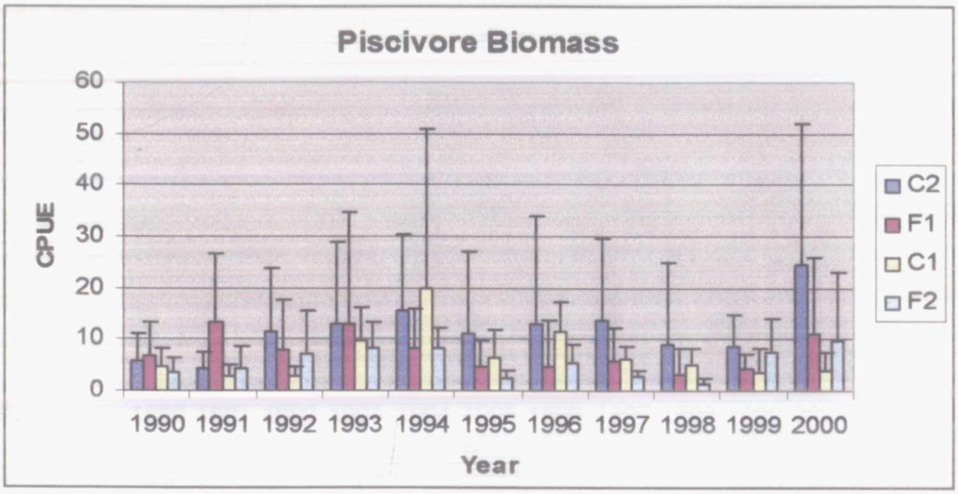
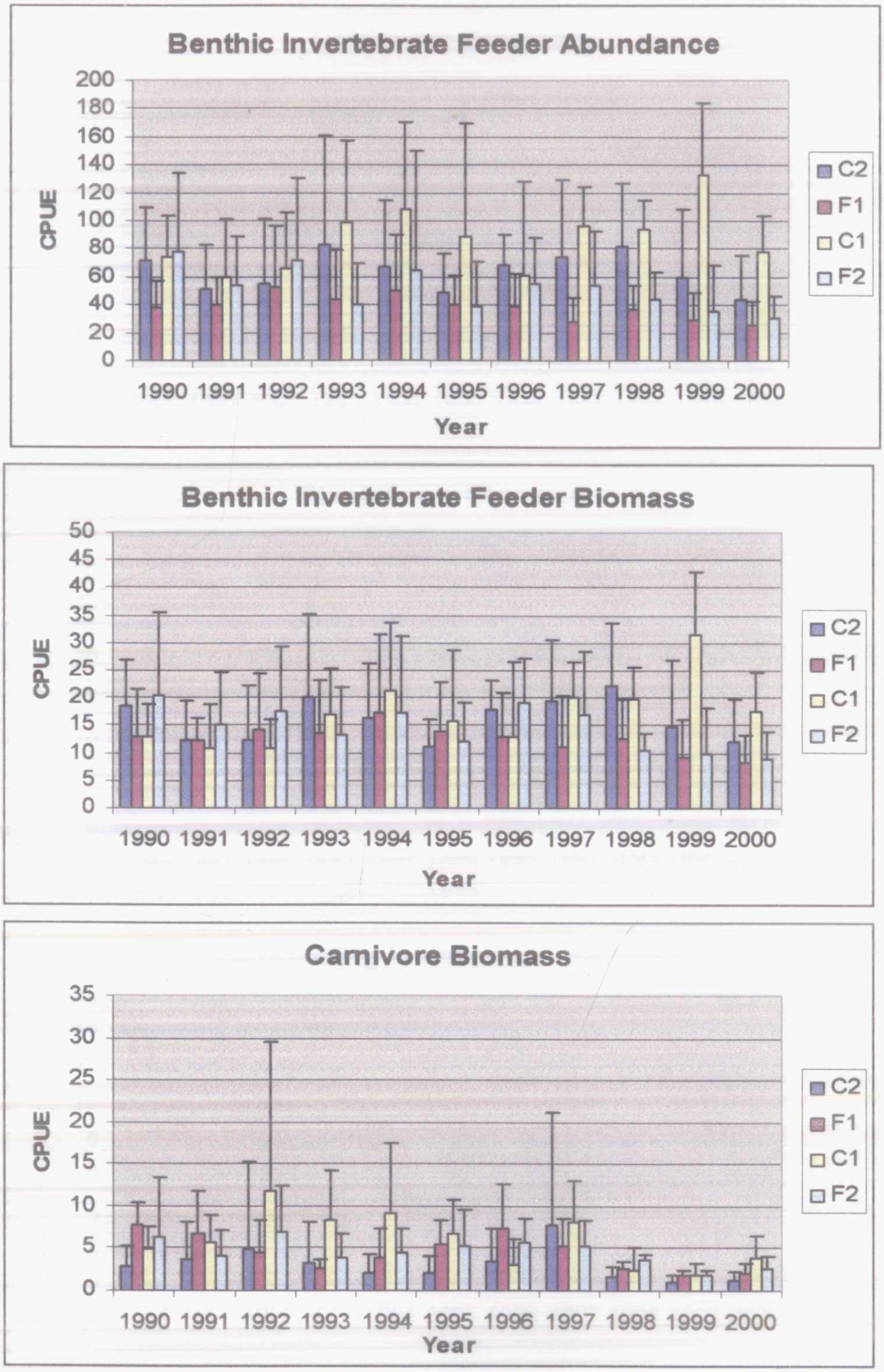


Figure 5: Averages of Abundance and Biomass of Functional Feeding Groups for Closed and Fished Areas in the Eastern Bering Sea. Changes in abundance, if measured, and biomass of each functional feeding group are shown for each area between the years 1990 and 2000.



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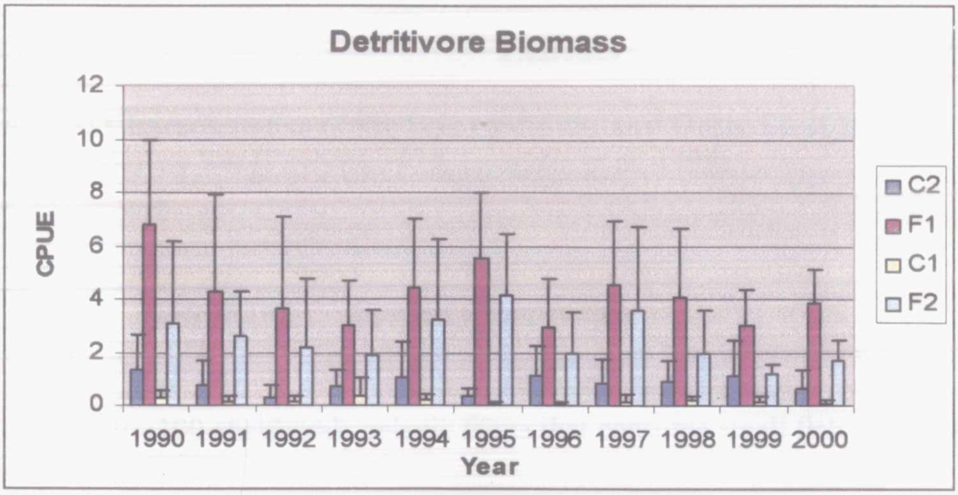
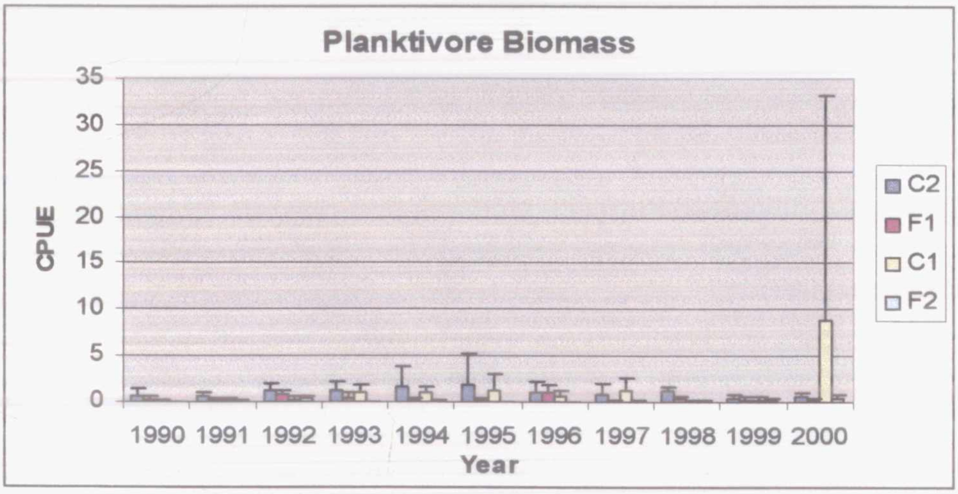




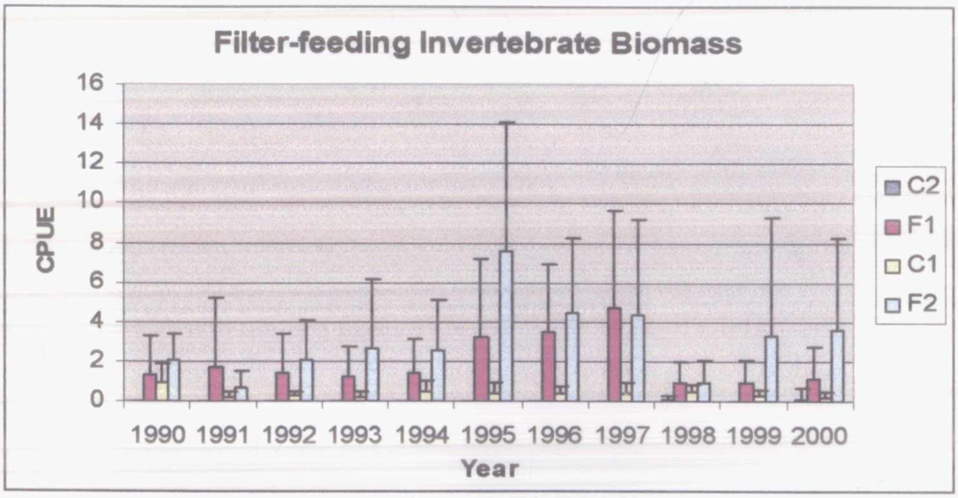


Figure 5 (Continued)

TABLES

Table 1: Characteristics of the Inner, Middle, and Outer Shelf Habitats of the Eastern Bering Sea (Favorite 1974, Loughlin et al 1999)

	Depth (m)	**Species Composition**
Inner Shelf	0-50	bottom-dwelling fauna that consume benthic infauna
Middle Shelf	50-100	bottom-dwelling fauna that consume benthic infauna
Outer Shelf	100-shelfbreak	pelagic fauna that consume small fish and euphausiids

Table 2: History of Closed Areas in the Eastern Bering Sea

Year	Area	Regulation	Reason	Reference
1959-1984	Bristol Bay Pot Sanctuary	Prohibit Japanese trawl vessels	Minimize crabpot-tanglenet interactions and prevent catch of juvenile groundfish	1, 2
1968-1983	Bristol Bay Pot Sanctuary	Bilateral agreements between U.S., Japan, and USSR	Protect fish stocks	3
1969	Pribilof Islands	Closed to foreign fishing	Protect fish stocks	4
1975	Winter Halibut Savings Area	Trawling prohibited seasonally	Control bycatch of herring	4
1983	All Bering Sea including closed areas	Open to a domestic trawl fishery	Allow domestic catches	2, 4
1987-present	Bristol Bay Pot Sanctuary, winter Halibut Savings Area, and Pribilof Islands	Closed to domestic trawl fisheries and implementation of a crab protection zone	Prevent incidental catch of adult red king crab	2, 4
1987-present	Area 512	Closed to trawling year-round	Protect red king crab mating grounds	2, 4
1989-present	Area 516	Closed annually from April 15-June 15	Protect molting red king crab	2, 4
1991-present	Herring Savings Areas	Closed seasonally to all trawling	Account for migration patterns to control bycatch	4
1995-present	Chum Salmon Savings Area	Closed to trawling in August	Reduce excessive bycatch of salmon in groundfish trawls	4
1995-present	Chinook Salmon Savings Area	Prohibit trawling if bycatch limits are attained in BSAI	Reduce excessive bycatch of salmon in groundfish trawls	4
1995-present	Pribilof Islands	Closed to trawling year-round	Allow crab species to increase in abundance, reduce bycatch of juvenile halibut and crab, and to allow an increase in undisturbed habitat.	5
1995-present	Red King Crab Savings Area and Nearshore Bristol Bay	Emergency rule to prohibit bottom trawling	Protect higher levels of adult Red King Crab and to lower bycatch levels of trawl fisheries	4
1996-present	Red King Crab Savings Area	Permanent closure as year-round, non-pelagic trawl closure area	Rebuild depressed stocks and revitalize surrounding stocks	4
1997-present	Nearshore Bristol Bay	Closure of Northern Bristol Bay to bottom trawling except yellowfin sole Area	Protect Red King Crab across all life-history stages to ensure survival and a more abundant stock	1
1	Livingston and Witherell 1999			
2	Ackley and Witherell 1999			
3	Fredin 1987			
4	Witherell and Pautzke 1997			
5	NPFMC 1994			

Table 3: Study Areas, Species Numbers, and Area Characteristics. The average bottom and surface temperature (+ std dev), average depth (+ std dev), bottom sediment (Smith and McConnaughey 1999), study area size, and shelf location (Favorite 1974) and numbers of species and dominant species of the Nearshore Bristol Bay Closure Area (C1), the Bristol Bay Red King Crab Savings Area (C2), Fished Area 1 (F1) and Fished Area 2 (F2).

	C1	C2	F1	F2
Bottom Temp. °C	2.5 (± 1.4)	2.1 (± 1.0)	1.5 (± 1.1)	1.1 (± 1.3)
Surface Temp. °C	4.6 (± 2.0)	6.1 (± 1.7)	6.0 (± 1.5)	6.1 (± 1.7)
Depth (m)	63.1 (± 2.2)	74.8 (± 2.2)	72.5 (±1.5)	63.8 (± 1.2)
Bottom Sediment	sand and mud	sand and mud	sand and mud	sand and mud
Area (nmi^2)	4,000	4,000	4,000	4,000
Shelf Location	middle shelf	middle shelf	middle shelf	middle shelf
# Species	108	101	144	107
# Dominant Species	14	21	35	22

Table 4: Dominant Species Abundance. Total number of individuals, not standardized by CPUE, of each species, dominant for abundance, captured within each area. Each species is represented by scientific name, common name, and abundance values for each area (C1, C2, F1, F2) and for all areas.

Chordata		**CA1**	**CA2**	**FA1**	**FA2**	**total #**
Atherestes stomias	arrowtooth flounder	285	2214	520	20	3039
Gadus macrocephalus	Pacific cod	12492	6687	5853	9110	34142
Hippoglossoides elassodon	flathead sole	17063	25737	18435	1664	62899
Lepidopsetta sp. cf. bilineata	northern rock sole	310736	137540	32359	83359	563994
Limanda aspera	yellowfin sole	112871	164853	117889	100115	495728
Mallotus villosus	capelin	1165	196	184	1021	2566
Pleuronectes quadrituberculatus	Alaskan plaice	8117	9646	8299	29375	55437
Podothecus acipenserinus	sturgeon poacher	9353	4962	1552	7317	23184
Theragra chalcogramma	walleye pollock	30258	75196	38455	30035	173944
Echinodermata						
Evasterias echinosoma	giant sea star	1099	179	13	0	1291
Arthropoda						
Paguridae	unidentified hermit crab	545	4148	9405	0	14098
Chionoecetes bairdi	Tanner crab	2847	6271	9009	720	18847
Chionoecetes opilio	narrow snow crab	103	1306	20718	77833	99960
Hyas spp	unidentified spider crabs	146	50	999	725	1920
Hyas lyratus	Pacific lyre crab	1195	537	1621	0	3353
Mollusca						
Buccinum spp	buccinum whelks	0	176	3810	2609	6595
Buccinum angulosum	angulated buccinum	4	6	3545	557	4112
Buccinum polare	polar whelk	0	62	11302	3508	14872
Buccinum scalariforme	ladder whelk	0	14	2898	2236	5148
Fusitriton oregonensis	Oregon triton	304	2238	426	0	2968
Neptunea spp	neptune whelks	198	104	4334	0	4636
Neptunea heros	northern neptune	736	1462	12238	19786	34222
Neptunea lyrata	lyre whelk	118	2726	15158	295	18297
Neptunea pribiloffensis	Pribilof whelk	0	6230	2057	28	8315
Neptunea ventricosa	fat whelk	726	2210	11882	10690	25508
Pyrulofusus deformis	warped whelk	0	22	6973	0	6995
Volutopsius spp	unidentified volute whelks	0	20	5223	9	5252
Volutopsius fragilis	fragile whelk	0	0	4165	24	4189
Cnidaria						
Chrysaora spp	sea nettles	2183	166	120	35	2504

Table 5: Dominant Species Biomass. Total biomass in kilograms of species, not standardized by CPUE, of each species, dominant for biomass, captured within each area. Each species is represented by scientific name, common name, and biomass for each area (C1, C2, F1, F2) and for all areas.

Chordata		**CA1**	**CA2**	**FA1**	**FA2**	**total #**
Atherestes stomias	arrowtooth flounder	190	1300	317	12	1819
Gadus macrocephalus	Pacific cod	8976	7705	7645	7403	31728
Hippoglossoides elassodon	flathead sole	6155	8618	10146	732	25653
Lepidopsetta sp. cf. bilineata	northern rock sole	49543	24899	6148	17266	97857
Limanda aspera	yellowfin sole	29449	45132	34952	28234	137767
Mallotus villosus	capelin	26	4	4	12	46
Pleuronectes quadrituberculatus	Alaskan plaice	4748	7148	7212	17175	36283
Podothecus acipenserinus	sturgeon poacher	788	408	78	386	1661
Theragra chalcogramma	walleye pollock	28027	53762	26393	17734	125916
Hemichordata						
Ascidian spp	unidentified Ascidians	21	3	291	445	759
Boltenia spp	sea onion	1915	12	46	3	1976
Halocynthia spp	sea peaches	0	0	940	2371	3311
Styela rustica	sea potato	109	131	7577	11710	19527
Echinodermata						
unidentified sea star spp	unidentified sea stars	6	0	823	150	979
Asterias amurensis	purple-orange sea star	28687	11974	3602	7156	51419
Evasterias echinosoma	giant sea star	810	426	14	0	1250
Gorgonocephalus eucnemis	basket star	497	838	2090	2120	5545
Leptasterias arctica	arctic sea star	0	<1	244	26	271
Leptasterias polares	knobby six-rayed sea star	0	0	3076	4	3080
Ophiuroid spp	unidentified brittlestars	0	0	2042	0	2042
Ophiura sarsi	notched brittlestar	3	12	2093	0	2108
Arthropoda						
Paguridae	unidentified hermit crabs	494	1638	8389	6947	17467
Chionoecetes bairdi	Tanner crab	1459	2240	1958	98	5755
Chionoecetes opilio	narrow snow crab	34	318	6192	9464	16008
Hyas spp	unidentified spider crabs	11	9	99	80	198
Hyas coarctatus	circumboreal toad crab	89	73	490	366	1018
Hyas lyratus	Pacific lyre crab	119	39	78	0	237
Pagurus spp	unidentified hermit crabs	5	107	0	358	471
Pagurus aleuticus	Aleutian hermit	62	483	801	0	1347
Mollusca						
Gastropoda spp	unidentified snails	6	4	497	111	618
Buccinum spp	unidentified buccinums	0	4	188	114	306
Buccinum angulosum	angulated buccinum	<1	<1	147	30	178
Buccinum polare	polar whelk	0	2	324	123	448
Buccinum scalariforme	ladder whelk	0	<1	135	95	230
Fusitriton oregonensis	Oregon triton	31	153	45	0	229
Neptunea spp	unidentified neptune whelks	40	60	469	0	570
Neptunea heros	northern neptune	130	321	2285	2130	4866
Neptunea lyrata	lyre whelk	13	436	2048	24	2521
Neptunea pribiloffensis	Pribilof whelk	0	1089	244	3	1336
Neptunea ventricosa	fat whelk	108	392	1727	1082	3310
Pyrulofusus deformis	warped whelk	0	3	954	0	957
Volutopsius spp	unidentified volute whelks	0	2	528	1	531
Volutopsius fragilis	fragile whelk	0	0	400	8	408

(Table 5 Continued)

Cnidaria		**CA1**	**CA2**	**FA1**	**FA2**	**total #**
Scyphozoa (class)	unidentified jellvfish	4715	4971	1536	490	11712
Chrysaora spp	sea nettles	652	77	49	26	805
Porifera						
Porifera	unidentified sponge	17475	20414	76	7	37972
Miscellaneous						
empty gastropod shells	empty gastropod shells	244	1983	3976	2449	8651

Table 6: Functional Feeding Groups (FFGs) of Dominant Species. Each species is assigned to a functional feeding group (FFG) based on type of prey consumed. Groups are Piscivores (PS), Benthic Invertebrate Feeders (B), Carnivores (C), Detritivores (D), Planktivores (PL), Filter-feeding Invertebrates (F), and Miscellaneous (M).

Species	Prey Species	FFG	References
Chordata			
Atherestes stomias	crustaceans, small fish	PS	5
Gadus macrocephalus	crustaceans, small fish	PS	3
Hippoglossoides elassodon	worms, crustaceans	B	5
Lepidopsetta sp. cf. bilineata	worms, crustaceans	B	5
Limanda aspera	worms, brittlestars	B	5
Mallotus villosus	worms, crustaceans	B	5,8
Pleuronectes quadrituberculatus	worms, amphipods	B	12
Podothecus acipenserinus	worms, crustaceans	B	2
Theragra chalcogramma	crustaceans, small fish	PS	5
Hemichordata			
Unidentified Ascidian spp	detritus, bacteria	F	9
Unidentified Boltenia spp	detritus, bacteria	F	9
Unidentified Halocynthia spp	detritus, bacteria	F	10
Styela rustica	invertebrate larvae	F	1
Echinodermata			
Unidentified sea stars	scavengers, worms	C	9
Asterias amurensis	scavengers, worms	C	9
Evasterias echinosoma	scavengers, worms	C	9
Gorgonocephalus eucnemis	scavengers, worms	C	6
Leptasterias arctica	scavengers, worms	C	9
Leptasterias polares	scavengers, worms	C	9
Ophiuroid spp	scavengers, worms	C	6
Ophiura sarsi	scavengers, worms	C	6
Arthropoda			
Paguridae	detritus, bacteria	D	9
Chionoecetes bairdi	small clams, worms	C	4
Chionoecetes opilio	small clams, worms	C	4
Hyas spp	detritus, bacteria	D	9
Hyas coarctatus	small clams, worms	C	4
Hyas lyratus	small clams, worms	C	4
Pagurus spp	detritus, bacteria	D	9
Pagurus aleuticus	detritus, bacteria	D	9
Mollusca			
Gastropoda spp	detritus, bacteria	D	9
Buccinum spp	detritus, bacteria	D	9
Buccinum angulosum	detritus, bacteria	D	9
Buccinum polare	detritus, bacteria	D	9
Buccinum scalariforme	detritus, bacteria	D	9
Fusitriton oregonensis	detritus, bacteria	D	9
Neptunea spp	detritus, bacteria	D	9
Neptunea heros	detritus, bacteria	D	9
Neptunea lyrata	detritus, bacteria	D	9
Neptunea pribiloffensis	detritus, bacteria	D	9
Neptunea ventricosa	detritus, bacteria	D	9
Pyrulofusus deformis	detritus, bacteria	D	9
Volutopsius spp	detritus, bacteria	D	9
Volutopsius fragilis	detritus, bacteria	D	9

(Table 6 Continued)

Cnidaria	**Prey Species**	**FFG**	**References**
Scyphozoa spp	copepods, small fish	PL	7
Chrysaora spp	copepods, small fish	PL	11
Porifera			
Porifera spp	detritus, bacteria	F	9
Empty Gastropod Shells		M	

References

1 Bingham and Walters 1989
2 Clemens and Wilby 1961
3 Cohen et al. 1990
4 Feder and Jewett 1986
5 Hart 1973
6 Hyman 1955
7 Kozloff 1996
8 Muus and Nielson 1999
9 O'Clair and O'Clair 1998
10 Ribes, Coma, and Gili 1998
11 Suchman and Sullivan 1998
12 Zhang 1988

Table 7: Comparisons of Total Abundance, Total Biomass, Diversity, and Evenness Among Areas, Among Years, for the Interaction of Area*Year, and Comparisons Between Combinations of Areas. Significant differences are shown among areas, among years, and the interaction term (area*year) for total biomass, total abundance, diversity and evenness. Combinations of areas were compared for differences in total biomass, total abundance, diversity, and evenness between Closed Area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2). Levels of significance (p< 0.01, p<0.001, p<0.0001) are shown where these differences occur. Non-significant estimates are denoted as N/S.

	area	year	area*year	C1|C2	C1|F1	C1|F2	C2|F1	C2|F2	F1|F2
Total Abundance	N/S	<0.001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Total Biomass	N/S	<0.0001	<0.001	N/S	N/S	N/S	N/S	N/S	N/S
Diversity	<0.0001	<0.001	<0.0001	N/S	<0.0001	N/S	<0.0001	N/S	N/S
Evenness	<0.01	N/S	<0.0001	N/S	<0.0001	N/S	<0.0001	N/S	N/S

Table 8: Significant Differences and Directions of Changes of Total Abundance, Total Biomass, Diversity, and Evenness. Significant differences are shown between aggregates of closed and fished areas, between aggregates of pre-closure (1990-1994) and post-closure (1996-2000) years, and between aggregates of pre- and post- closure years within each area. Areas are defined as Closed area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2). Differences in closed areas versus fished areas are depicted yellow for a significantly greater fished area. Decreases over time are in red, increases in green, and no change is in white. Non-significant changes are depicted by N/S.

	Closed/Fished	Before/After	C1	C2	F1	F2
Total Abundance	N/S	N/S	N/S	N/S	N/S	<0.001
Total Biomass	N/S	N/S	N/S	<0.01	N/S	N/S
Diversity	<0.0001	<0.0001	N/S	N/S	<0.0001	N/S
Evenness	<0.01	N/S	N/S	N/S	N/S	N/S

Table 9: Comparisons of Abundance and Biomass of *Paralithodes camtschaticus* Among Areas, Among Years, for the Interaction of Area*Year, and Comparisons Between Combinations of Areas. Significant differences are shown among areas, among years, and for the interaction term (area*year) for abundance and biomass of *Paralithodes camtschaticus*. Pairs of areas were compared for differences in abundance and biomass. Closed Area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2) are denoted below. Non-significant estimates are denoted by N/S.

				Area Combinations					
	area	year	area*year	C1|C2	C1|F1	C1|F2	C2|F1	C2|F2	F1|F2
Abundance	<0.0001	<0.01	<0.01	N/S	<0.0001	<0.0001	<0.0001	<0.0001	N/S
Biomass	<0.0001	N/S	N/S	N/S	<0.0001	<0.0001	<0.0001	<0.0001	N/S

Table 10: Significant Differences in Abundance and Biomass and Direction of Changes of *Paralithodes camtschaticus.* Significant differences in abundance and biomass are shown between aggregates of closed and fished areas (C/F), between aggregates of pre-closure (1990-1994) and post-closure (1996-2000) years (B/A), and between aggregates of pre- and post- closure years within each area. Areas are defined as Closed area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2). Differences in closed areas versus fished areas are in blue for significantly greater closed area. Increases over time are in green and no change is in white. Non-significant changes are depicted by N/S.

	Closed/Fished	Before/After	C1	C2	F1	F2
Abundance	<0.0001	N/S	<0.01	<0.01	N/S	N/S
Biomass	<0.0001	N/S	N/S	<0.001	N/S	N/S

Table 11: Comparisons of Abundance of Dominant Species Among Areas, Among Years, for the Interaction of Area*Year, and Comparisons Between Combinations of Areas. Significant differences are shown among areas, among years, and for the interaction term (area*year) for abundance, if measured, of each dominant species. Pairs of areas were compared for differences in abundance of each species. Closed Area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2) are denoted below. Non-significant estimates are denoted by N/S. Refer to Table 5 for common names.

				Area Combinations					
Chordata	**area**	**year**	**area* year**	**C1|C2**	**C1|F1**	**C1|F2**	**C2|F1**	**C2|F2**	**F1|F2**
Atherestes stomias	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Gadus macrocephalus	<0.01	<0.0001	<0.001	N/S	N/S	N/S	N/S	N/S	N/S
Hippoglossoides elassodon	<0.01	<0.001	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Lepidopsetta sp. cf. bilineata	<0.01	<0.01	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Limanda aspera	N/S	<0.001	<0.01	N/S	N/S	N/S	N/S	N/S	N/S
Mallotus villosus	N/S	<0.0001	<0.001	N/S	N/S	N/S	N/S	N/S	N/S
Pleuronectes quadrituberculatus	N/S	N/S	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Podothecus acipenserinus	N/S	<0.001	<0.01	N/S	N/S	N/S	N/S	N/S	N/S
Theragra chalcogramma	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Echinodermata									
Evasterias echinosoma	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Arthropoda									
Chlonoecetes bairdi	<0.0001	<0.0001	<0.001	N/S	N/S	<0.0001	N/S	<0.0001	<0.0001
Chlonoecetes opilio	<0.0001	<0.0001	<0.0001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	N/S
Hyas spp	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Hyas lyratus	N/S	<0.01	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Pagurus spp	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Mollusca									
Buccinum spp	<0.0001	<0.0001	<0.0001	N/S	<0.001	<0.0001	<0.001	<0.0001	N/S
Buccinum angulosum	<0.0001	<0.0001	<0.0001	N/S	<0.0001	N/S	<.0001	N/S	N/S
Buccinum polare	<0.0001	<0.0001	<0.0001	N/S	<0.001	N/S	<0.001	N/S	N/S
Buccinum scalariforme	<0.0001	<0.001	<0.0001	N/S	<0.0001	<0.001	<0.0001	<0.001	N/S
Fusitriton oregonensis	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Neptunea spp	N/S	N/S	<0.01	N/S	N/S	N/S	N/S	N/S	N/S
Neptunea heros	<0.01	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Neptunea lyrata	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Neptunea pribiloffensis	N/S	<0.01	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Neptunea ventricosa	N/S	<0.001	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Pyrulofusus deformis	<0.01	N/S	<0.01	N/S	N/S	N/S	N/S	N/S	N/S
Volutopsius spp	<0.01	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Volutopsius fragilis	<0.0001	<0.0001	<0.0001	N/S	<0.001	N/S	<0.0001	N/S	N/S
Cnidaria									
Chrysaora spp	N/S	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S	N/S

Table 12: Significant Differences in Abundance and Direction of Changes of Dominant Species. Significant differences in abundance, if measured, are shown between aggregates of closed and fished areas (C/F), between aggregates of pre-closure (1990-1994) and post-closure (1996-2000) years (B/A), and between aggregates of pre- and post- closure years within each area. Areas are defined as Closed area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2). Differences in closed areas versus fished areas are in blue for significantly greater closed area and yellow for a significantly greater fished area. Decreases over time are in red, increases in green, and no change is in white. Non-significant changes are depicted by N/S.

Chordata	C/F	B/A	C1	C2	F1	F2
Atherestes stomias	N/S	<0.0001	<0.0001	<0.0001	N/S	N/S
Mallotus villosus	N/S	N/S	<0.01	N/S	N/S	N/S
Pleuronectes quadrituberculatas	N/S	N/S	<0.0001	N/S	N/S	N/S
Theragra chalcogramma	N/S	<0.01	N/S	N/S	<0.001	N/S
Arthropoda						
Hyas spp	N/S	<0.0001	N/S	N/S	<0.0001	<0.01
Chionoecetes bairdi	<0.001	<0.0001	<0.0001	<0.001	N/S	<0.0001
Chionoecetes opilio	<0.0001	<0.0001	<.001	<0.0001	N/S	N/S
Pagurus aleuticus	N/S	<0.0001	<0.0001	<0.0001	<0.0001	N/S
Mollusca						
Buccinum spp	<0.0001	<0.0001	N/S	N/S	N/S	<0.0001
Volutopsius spp	<0.01	N/S	N/S	N/S	<0.01	N/S
Buccinum angulosum	<0.0001	N/S	N/S	N/S	<.001	N/S
Buccinum polare	<0.0001	N/S	N/S	N/S	N/S	<0.01
Buccinum scalariforme	<0.0001	N/S	N/S	N/S	N/S	N/S
Neptunea heros	<0.01	<0.0001	N/S	N/S	<0.0001	<0.0001
Neptunea pribiloffensis	N/S	N/S	N/S	N/S	N/S	N/S
Volutopsius fragilis	<0.001	<0.0001	N/S	N/S	<0.0001	N/S

Table 13: Comparisons of Biomass of Dominant Species Among Areas, Among Years, for the Interaction of Area*Year and Comparisons Between Combinations of Areas. Significant differences are shown among areas, among years, and for area*year for biomass of each dominant species. Pairs of areas were compared for differences in biomass of each species. Closed Area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2) are denoted below. Non-significant estimates are denoted by N/S.

				Area Combinations					
Chordata	**area**	**year**	**area*year**	**C1|C2**	**C1|F1**	**C1|F2**	**C2|F1**	**C2|F2**	**F1|F2**
Atherestes stomias	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Gadus macrocephalus	N/S	<0.0001	<0.01	N/S	N/S	N/S	N/S	N/S	N/S
Hippoglossoides elassodon	<0.0001	<0.01	N/S	N/S	N/S	<0.0001	N/S	<0.0001	<0.0001
Lepidopsetta sp. cf. bilineata	<0.01	<0.0001	N/S	N/S	<0.001	N/S	N/S	N/S	N/S
Limanda aspera	N/S	<0.0001	<0.01	N/S	N/S	N/S	N/S	N/S	N/S
Mallotus villosus	N/S	<0.01	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Pleuronectes quadrituberculatus	N/S	N/S	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Podothecus acipenserinus	<0.01	<0.0001	<0.01	N/S	N/S	N/S	N/S	N/S	N/S
Theragra chalcogramma	<0.01	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Hemichordata									
Ascidian spp	N/S	<0.0001	<0.001	N/S	N/S	N/S	N/S	N/S	N/S
Boltenia spp	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001	N/S	N/S	N/S
Halocynthia spp	<0.01	<0.0001	<0.001	N/S	N/S	N/S	N/S	<0.01	N/S
Styela rustica	<0.0001	<0.0001	<0.0001	N/S	N/S	<0.001	N/S	<0.001	N/S
Echinodermata									
Unidentified sea stars	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Asterias amurensis	N/S	N/S	<0.001	N/S	N/S	N/S	N/S	N/S	N/S
Evasterias echinosoma	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Gorgonocephalus eucnemis	<0.0001	<0.0001	N/S	N/S	N/S	N/S	<0.0001	<0.001	N/S
Leptasterias arctica	<0.001	<0.001	<0.0001	N/S	N/S	N/S	<0.001	N/S	N/S
Leptasterias polaris	<0.0001	<0.0001	<0.0001	N/S	<0.0001	N/S	<0.0001	N/S	<0.0001
Ophiuroid unidentified	<0.0001	N/S	<0.01	N/S	<0.0001	N/S	<0.0001	N/S	<0.0001
Ophiura sarsi	<0.0001	N/S	<0.001	N/S	<0.0001	N/S	<0.0001	N/S	<0.0001
Arthropoda									
Paguridae	N/S	<0.0001	<0.001	N/S	<0.001	<0.001	N/S	N/S	N/S
Chionoecetes bairdi	<0.0001	<0.0001	<0.0001	N/S	N/S	<0.0001	N/S	<0.0001	<0.0001
Hyas spp	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Hyas coarctatus	<0.001	<0.001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Hyas lyratus	N/S	<0.001	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Chionoecetes opilio	<0.0001	<0.0001	<0.0001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	N/S
Pagurus spp	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Pagurus aleuticus	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Mollusca									
Gastropoda spp	<0.01	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Buccinum spp	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Buccinum angulosum	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Buccinum polare	<0.01	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Buccinum scalariforme	<0.0001	<0.001	<0.0001	N/S	<0.0001	<0.001	<0.0001	<0.001	N/S
Fusitriton oregonensis	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Neptunea spp	N/S	<0.001	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Neptunea heros	<0.01	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Neptunea lyrata	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Neptunea pribiloffensis	N/S	<0.01	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Neptunea ventricosa	N/S	<0.01	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Pyrulofusus deformis	<0.01	N/S	<0.01	N/S	N/S	N/S	N/S	N/S	N/S
Volutopsius spp	<0.01	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Volutopsius fragilis	<0.001	<0.0001	<0.0001	N/S	<0.001	N/S	<0.001	N/S	<0.001
Cnidaria									
Scyphozoa spp	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Chrysaora spp	N/S	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Porifera									
Porifera spp	<0.01	<0.001	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Miscellaneous									
Empty Gastropod Shells	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S

Table 14: Significant Differences in Biomass and Direction of Changes of Dominant Species. Significant differences in biomass are shown between aggregates of closed and fished areas (C/F), between aggregates of pre-closure (1990-1994) and post-closure (1996-2000) years (B/A), and between aggregates of pre- and post- closure years within each area. Areas are defined as Closed area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2). Differences in closed areas versus fished areas are in blue for significantly greater closed area and yellow for a significantly greater fished area. Decreases over time are in red, increases in green, and no change is in white. Non-significant changes are depicted by N/S.

Chordata	**C/F**	**B/A**	**C1**	**C2**	**F1**	**F2**
Atherestes stomias	N/S	<0.0001	<0.0001	<0.0001	N/S	N/S
Mallotus villosus	N/S	N/S	<0.01	N/S	N/S	<0.01
Pleuronectes quadrituberculatas	N/S	N/S	<0.0001	N/S	N/S	N/S
Theragra chalcogramma	<0.01	N/S	N/S	N/S	<0.0001	N/S
Hemichordata						
Ascidian spp	N/S	<0.001	N/S	N/S	N/S	<0.0001
Boltenia spp	N/S	N/S	<0.001	N/S	N/S	N/S
Halocynthia spp	N/S	<0.0001	N/S	N/S	N/S	<0.0001
Styela rustica	<0.0001	<0.0001	N/S	N/S	<0.0001	<0.0001
Echinodermata						
Sea star unidentified	N/S	<0.0001	N/S	N/S	<0.0001	<0.001
Asterias amurensis	N/S	0.0367	<0.01	N/S	<0.01	<0.001
Leptasterias arctica	<0.001	<0.0001	N/S	N/S	<0.0001	<0.0001
Leptasterias polaris	<0.0001	<0.01	N/S	N/S	<0.0001	N/S
Ophiura sarsi	<0.0001	<.001	N/S	N/S	<0.0001	N/S
Arthropoda						
Hyas spp	N/S	<0.0001	N/S	N/S	<0.0001	<0.001
Pagurus spp	N/S	<0.0001	N/S	<0.0001	N/S	<0.0001
Chionoecetes bairdi	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chionoecetes opilio	<0.0001	<0.0001	<.001	<0.0001	N/S	<0.0001
Hyas coarctatus	<0.0001	N/S	N/S	N/S	N/S	N/S
Pagurus aleuticus	N/S	<0.0001	<0.0001	<0.0001	<0.0001	N/S
Mollusca						
Gastropoda spp	<0.01	<0.01	N/S	N/S	<0.01	<0.01
Buccinum spp	N/S	<0.01	N/S	N/S	N/S	<0.001
Volutopsius spp	<0.01	N/S	N/S	N/S	N/S	N/S
Buccinum angulosum	<0.01	N/S	N/S	N/S	<.001	N/S
Buccinum polare	<0.01	N/S	N/S	N/S	N/S	N/S
Buccinum scalariforme	<0.0001	N/S	N/S	N/S	N/S	N/S
Neptunea heros	<0.01	<0.0001	N/S	N/S	<0.0001	<0.0001
Neptunea pribiloffensis	N/S	N/S	N/S	N/S	N/S	N/S
Volutopsius fragilis	<0.001	<0.0001	N/S	N/S	<0.0001	N/S
Cnidaria						
Scyphozoa spp	<0.01	N/S	N/S	N/S	N/S	<0.01
Miscellaneous						
Empty Gastropod Shells	N/S	<0.0001	<0.0001	N/S	<0.0001	<0.0001

Table 15: Comparisons of Abundance of Functional Feeding Groups Among Areas, Among Years, for the Interaction of Area*Year, and Comparisons Between Combinations of Areas. Significant differences in abundance, if measured, are shown among areas, among years, and for the interaction term (area*year) for functional feeding groups. Combinations of areas were compared for differences in abundance of functional feeding groups. Areas are defined as Closed Area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2). Non-significant estimates are denoted by N/S.

				Area Combinations					
Functional Group	**area**	**year**	**area*year**	**C1|C2**	**C1|F1**	**C1|F2**	**C2|F1**	**C2|F2**	**F1|F2**
Piscivores	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Benthic Invertebrate Feeders	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S

Table 16: Significant Differences in Abundance and Direction of Changes of Functional Feeding Groups. Significant differences in abundance, if measured, are shown between aggregates of closed and fished areas (C/F), between aggregates of pre-closure (1990-1994) and post-closure (1996-2000) years (B/A), and between aggregates of pre- and post- closure years within each area. Areas are defined as Closed area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2). Decreases over time are in red and no change is in white. Non-significant changes are depicted by N/S.

Functional Group	C/F	B/A	C1	C2	F1	F2
Piscivores	N/S	<0.01	N/S	N/S	<0.001	<0.01
Benthic Invertebrate Feeders	N/S	N/S	N/S	N/S	N/S	N/S

Table 17: Comparisons of Biomass of Functional Feeding Groups Among Areas, Among Years, for the Interaction of Area*Year, and Comparisons Between Combinations of Areas. Significant differences in biomass are shown among areas, among years, and for the interaction term (area*year) for functional feeding groups. Combinations of areas were compared for differences in biomass of functional feeding groups. Areas are defined as Closed Area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2). Non-significant estimates are denoted by N/S.

				Area Combinations					
Functional Group	**area**	**year**	**area* year**	**C1|C2**	**C1|F1**	**C1|F2**	**C2|F1**	**C2|F2**	**F1|F2**
Piscivores	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Benthic Invertebrate Feeders	N/S	N/S	<0.0001	N/S	N/S	N/S	N/S	N/S	N/S
Carnivores	N/S	<0.0001	<0.01	N/S	N/S	N/S	N/S	N/S	N/S
Detritivores	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Planktivores	N/S	<0.0001	<0.0001	N/S	N/S	N/S	N/S	<0.01	N/S
Filter-feeding Invertebrates	<0.0001	<0.001	<0.0001	<0.0001	<0.001	N/S	N/S	N/S	N/S

Table 18: Significant Differences in Biomass and Direction of Changes of Functional Feeding Groups. Significant differences in biomass are shown between aggregates of closed and fished areas (C/F), between aggregates of pre-closure (1990-1994) and post-closure (1996-2000) years (B/A), and between aggregates of pre- and post- closure years within each area. Areas are defined as Closed area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2). Differences in closed areas versus fished areas are in blue for significantly greater closed area and yellow for a significantly greater fished area. Decreases over time are in red, increases in green, and no change is in white. Non-significant changes are depicted by N/S.

Functional Group	C/F	B/A	C1	C2	F1	F2
Piscivores	N/S	N/S	N/S	N/S	<0.001	N/S
Benthic Invertebrate Feeders	N/S	N/S	<0.0001	N/S	N/S	N/S
Carnivores	N/S	<0.001	<0.0001	N/S	N/S	N/S
Detritivores	<0.001	N/S	N/S	N/S	N/S	N/S
Planktivores	<0.01	N/S	N/S	N/S	N/S	<0.001
Filter-feeding Invertebrates	N/S	N/S	<0.01	N/S	N/S	<0.0001

APPENDICES

Appendix 1: Definition of Marine Protected Areas

Marine protected areas are defined as "any area of intertidal or subtidal terrain together with its overlying water and associated flora, fauna, historical, and cultural features which has been reserved by law or other effective means to protect all or part of the enclosed environment" (Kelleher and Kenchington 1992).

Although many marine protected areas occur in tropical environments, which can be conducive to organisms with more sedentary lifestyles and therefore allow for extensive protection of all species that do not emigrate from the marine protected area (Bohnsack 1993) they do occur in temperate environments (i.e. Nantucket Lightship Closed Area, Georges Bank) (Murawski et al. 2000).

Protection resulting from marine protected areas can range from total to minimal or absent. Strict Nature Reserves are maintained as undisturbed areas available for scientific or environmental research (NRC 2001). Wilderness Areas are naturally undisturbed and are maintained for future generation enjoyment. National Parks allow limited public use to protect areas of national and international significance (NRC 2001). Natural Monuments and Landmarks are maintained in a natural state and closed to extractive uses (NRC 2001). Habitat/Species Management Areas are conservation areas maintained to protect specific ecosystem components and offer varying levels of protection based on management objectives (NRC 2001). Protected Landscapes and Seascapes are areas of distinct character where ecological and cultural activities are balanced (NRC 2001). Marine Resource Protected Areas are maintained for sustainable use through management (NRC 2001).

Along with many potential benefits to marine protected areas, there are also costs to implementation of protected areas. These include direct costs such as those associated with enforcement and education, indirect costs on non-protected species surrounding the protected area and on relocation of fisheries, and opportunity costs occurred because all traditional practices are stopped within a marine protected area (Dixon 1993).

Appendix 2: Specific Coordinates for Study Areas in the Eastern Bering Sea.

Nearshore Bristol Bay Closure Area (C1)
57°66.66'N, 160°W
57°66.66'N, 162°W
56°66.66'N, 162°W
56°66.66'N, 160°W

Bristol Bay Red King Crab Savings Area (C2)
56°N, 162°W
56°N, 164°W
57°N, 164°W
57°N, 162°W

Fished Area 1 (F1)
57°33.33'N, 165°W
56°33.33'N, 165°W
56°33.33'N, 167°W
57°33.33'N, 167°W

Fished Area 2 (F2)
58°66.66'N, 168°W
57°66.66'N, 168°W
57°66.66'N, 170°W
58°66.66'N, 170°W

Appendix 3: Proc Mixed Models. The following models were used to estimate significant differences of dominant species between areas and years for biomass and abundance, respectively.

```
For Biomass:
data;
input zone $ year lat long biomass;
biomass= 1000*biomass;
lgbio = log(biomass + 1);
cards;
run;
proc mixed scoring = 50 convh=1e-06;
class zone year;
model lgbio=zone year zone*year/ddfm=satterth;
parms (.25 to 1.0 by .25) (.25 to 1.0 by .25) (1.0 to 50 by 5)/noiter;
repeated/ subject = intercept local type = sp(sph) (lat long);
lsmeans zone/pdiff adjust=tukey;
title 'arrowtooth flounder biomass';
run;
For Abundance:
data;
input zone $ year lat long abundance;
abundance= 1000*abundance;
lgab = log(abundance + 1);
cards;
run;
proc mixed scoring = 50 convh=1e-06;
class zone year;
model lgab=zone year zone*year/ddfm=satterth;
parms (.25 to 1.0 by .25) (.25 to 1.0 by .25) (1.0 to 50 by 5)/noiter;
repeated/ subject = intercept local type = sp(sph) (lat long);
lsmeans zone/pdiff adjust=tukey;
title 'arrowtooth flounder abundance';
run;
```

Appendix 4: F values associated with SAS comparisons among areas, among years, and of the interaction of area*year and t values associate with comparisons between pairs of areas. F and t values are listed below for total abundance, total biomass, diversity, evenness, abundance and biomass of functional groups, *Paralithodes camtschaticus*, and abundance and biomass of dominant species. The areas are described as Closed Area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2). Comparisons between pairs of these areas are listed below.

Table 19: F and t Values

	F-value			t-value					
	area	**year**	**area*year**	**C1|C2**	**C1|F1**	**C1|F2**	**C2|F1**	**C2|F2**	**F1|F2**
Total Abundance	0.65	3.3	2.6	0.91	1.37	0.5	0.59	-0.35	-0.85
Total Biomass	0.77	4.41	2.17	-0.03	0.75	1.22	0.83	1.29	0.46
Diversity	15.59	3.1	2.93	-1.82	-6.54	-2.79	-5.19	-1.13	3.7
Evenness	8.58	1.28	2.55	-2.36	-5.05	-2.49	-3.06	-0.29	2.53
Functional Groups-Abundance									
Piscivores	0.7	5.18	2.43	-1.08	0.17	0.02	1.26	1.06	-0.14
Benthic Invertebrate Feeders	3.04	1.36	1.6	1.07	2.9	1.53	2.12	0.57	-1.33
Functional Groups-Biomass									
Piscivores	0.99	5.36	2.48	-0.77	0.18	0.93	0.97	1.7	0.74
Benthic Invertebrate Feeders	1.3	1.86	2.42	0.49	1.84	0.54	1.54	0.09	-1.27
Carnivores	4.01	4.59	1.78	2.73	0.03	-0.14	-2.71	-2.78	-0.17
Detritivores	5.64	1.99	1.3	-1.85	-3.37	-3.53	-1.92	-1.98	-0.3
Planktivores	20.65	6.51	5.42	-2.89	0.79	4.94	3.64	7.82	4.06
Filter-feeding Invertebrates	13.06	3.68	3.27	5.75	5.16	3.29	-0.26	-2.15	-1.82
Paralithodes camtschaticus-abundance	60.37	2.41	1.87	2.89	10.59	10.01	8.92	7.69	-0.26
Paralithodes camtschaticus-biomass	60.09	2.24	1.73	2.04	10.22	9.62	9.4	8.09	-0.28
Dominant Species-Abundance									
Chordata									
Atherestes stomias	4.68	12.11	2.76	-2.31	-0.59	1.3	1.84	3.64	1.91
Gadus macrocephalus	4.8	4.63	2.17	3.36	3.12	1.63	0.02	-1.57	-1.48
Hippoglossoides elassodon	17.48	3.69	1.65	-0.9	0.04	5.59	0.99	6.75	5.58
Lepidopsetta sp. cf. bilineata	13.58	2.94	1.32	2.61	6.26	3.51	4.07	1.11	-2.68
Limanda aspera	0.48	3.55	1.94	-0.04	0.91	0.19	1.13	0.24	-0.7
Mallotus villosus	5.42	5.58	2.35	3.66	3.38	2.09	-0.07	-1.38	-1.25
Pleuronectes quadrituberculatus	3.97	0.46	3	-0.75	0.09	-2.92	0.95	-2.4	-3.1
Podothecus acipenserinus	8.41	3.15	1.7	2.96	4.68	1	1.99	-1.83	-3.6
Theragra chalcogramma	2.37	3.81	2.68	-2.54	-0.6	-0.99	1.87	1.44	-0.38
Echinodermata									
Evasterias echinosoma	2.47	0.94	1.16	0.64	2.01	2.24	1.57	1.74	0.28
Arthropoda									
Hyas spp	2.42	6.39	3.27	0.55	-2.04	-0.56	-2.57	-1.08	1.42
Pagurus spp	5.36	20.63	4.33	-1.63	0.15	2.39	1.74	4	2.19
Chionoecetes bairdi	47.11	12.19	2.35	-3.5	-3.53	6.99	-0.24	10.57	10.33
Chionoecetes opilio	79.09	16.7	7.73	-5.5	-11.75	-13.61	-7.05	-8.79	-1.92
Hyas lyratus	2.98	2.97	1.04	0.76	0.85	2.85	0.15	2.27	2.03

(Table 19 Continued)

Mollusca	area	year	area*year	C1|C2	C1|F1	C1|F2	C2|F1	C2|F2	F1|F2
Buccinum spp	23.8	9.14	5.62	-0.23	-5.63	-6.49	-5.4	-6.26	-0.88
Neptunea spp	1.86	2.26	1.92	0.45	-1.22	1.15	-1.66	0.72	2.28
Volutopsius spp	24.17	7.25	7.32	0.07	-7.04	-0.13	-7.28	-0.2	6.72
Buccinum angulosum	12.53	3.94	3.04	0.13	-5.08	-1.93	-5.57	-2.12	3.08
Buccinum polare	13.59	6.56	3.44	-0.05	-4.9	-3.52	-5.3	-3.65	1.34
Buccinum scalariforme	23.38	3.47	2.93	-0.31	-6.63	-5.21	-6.49	-5	1.38
Fusitriton oregonensis	1.59	0.86	1.05	-0.77	-0.29	1.32	0.52	2.16	1.64
Neptunea heros	5.5	7.49	2.39	-0.31	-1.4	-3.58	-1.32	-3.54	-2.3
Neptunea lyrata	3.93	1.61	1.47	-1.79	-2.69	0.35	-1.18	2.12	3.01
Neptunea pribiloffensis	3.46	2.54	2.44	-2.66	-1.95	-0.01	0.68	2.58	1.91
Neptunea ventricosa	2.3	3.1	1.67	0.07	-0.61	-2.2	-0.78	-2.41	-1.64
Pyrulofusus deformis	9.45	2.06	2.04	-0.36	-4.31	0.01	-4.44	0.35	4.26
Volutopsius fragilis	15	8.93	9.09	-0.03	-5.64	-0.38	-5.79	-0.35	5.13
Cnidaria									
Chrysaora spp	0.85	31.59	1.63	0.88	0.69	1.59	-0.16	0.76	0.88
Dominant Species-Biomass									
Chordata									
Atherestes stomias	4.6	13.4	3.05	-2.35	-0.67	1.23	1.78	3.59	1.92
Gadus macrocephalus	0.4	4.38	1.94	0.99	0.48	0.86	-0.49	-0.07	0.38
Hippoglossoides elassodon	23.62	2.9	1.66	-0.88	-0.52	6.46	0.33	7.54	6.9
Lepidopsetta sp. cf. bilineata	14.13	4.28	1.74	2.3	6.35	3.14	4.49	1.03	-3.14
Limanda aspera	0.27	5.15	2.03	-0.3	0.46	-0.04	0.89	0.24	-0.5
Mallotus villosus	4.43	2.94	2.47	3.35	3.01	1.97	-0.15	-1.2	-1.01
Pleuronectes quadrituberculatus	4.11	0.54	3.25	-1.18	-0.43	-3.22	0.83	-2.29	-2.89
Podothecus acipenserinus	10.84	4.51	1.92	3.29	5.6	1.96	2.69	-1.15	-3.56
Theragra chalcogramma	4.95	4.06	2.76	-2.45	0.83	0.94	3.19	3.31	0.1
Hemichordata									
Ascidian spp	4.55	3.78	2.36	-0.05	-0.69	-3.16	-0.77	-3.35	-2.58
Boltenia spp	71.97	3.38	2.02	11.78	11.82	12.2	0.68	1.08	0.39
Halocynthia spp	3.94	5.75	4.46	0.06	-0.63	-2.92	-0.76	-3.12	-2.31
Styela rustica	11.48	6.16	4.12	-0.35	-2.95	-4.83	-3.11	-4.83	-2.06
Echinodermata									
Sea star unidentified	3.28	9.42	3.86	0.19	-2.52	-1.4	-2.76	-1.6	1.09
Ophiuroid unidentified	68.73	2.07	2.02	0.01	-12	0	-12	-0.01	11.51
Asterias amurensis	6.17	1.66	2.15	2.57	4.05	0.93	1.83	-1.51	-3.06
Evasterias echinosoma	2.43	0.66	1.22	0.53	1.95	2.19	1.61	1.79	0.28
Gorgonocephalus eucnemis	14.08	5.77	1.07	0.39	-4.11	-3.76	-5.34	-4.41	0.2
Leptasterias arctica	10.17	3.6	3.66	0.14	-4.32	-2.25	-4.97	-2.5	2
Leptasterias polaris	45.33	4.42	4.15	-0.13	-9.29	-0.37	-10.24	-0.26	8.79
Ophiura sarsi	38.73	2.33	2.14	-0.2	-8.94	0.21	-8.87	0.4	8.87

(Table 19 Continued)

Arthropoda	**area**	**year**	**area*year**	**C1|C2**	**C1|F1**	**C1|F2**	**C2|F1**	**C2|F2**	**F1|F2**
Paguridae	13.63	19.92	1.73	-2.34	-4.92	-5.64	-2.91	-3.59	-0.75
Hyas spp	3.21	8.29	4.02	0.28	-2.53	-1.06	-2.82	-1.33	1.42
Pagurus spp	1.58	10.66	4.92	-0.54	0.32	-1.73	0.87	-1.25	-2.02
Chionoecetes bairdi	45.79	21.81	2.92	-2.93	-2.29	7.65	0.5	10.77	9.82
Hyas coarctatus	9.73	3.18	2.83	-0.11	-2.95	-4.37	-3.05	-4.43	-1.42
Hyas lyratus	3.14	3.18	1	1.16	1.09	3.02	0	2.05	1.96
Chionoecetes opilio	104.62	9.34	8.6	-5.41	-13.62	-15.12	-9.14	-10.44	-1.58
Pagurus aleuticus	3.94	20.77	3.53	-1.57	-0.78	1.76	0.74	3.33	2.49
Mollusca									
Gastropoda spp	24.95	7.74	4.02	0.11	-7.45	-3.12	-7.59	-3.23	4.16
Buccinum spp	22.24	6.23	4.81	-0.2	-5.65	-6.08	-5.47	-5.89	-0.46
Neptunea spp	1.49	3.55	1.37	0.42	-0.71	1.42	-1.11	1.03	2.06
Volutopsius spp	22.03	7.19	7.27	0.07	-6.71	-0.1	-6.95	-0.17	6.44
Buccinum angulosum	12.73	4.09	3.05	0.18	-5.1	-1.78	-5.64	-2.02	3.25
Buccinum polare	9.17	7.41	3.52	0.03	-3.95	-2.81	-4.45	-2.98	1.07
Buccinum scalariforme	27.09	3.43	3.05	-0.19	-7.16	-5.43	-7.11	-5.32	1.67
Fusitriton oregonensis	1.55	1.07	1.05	-0.8	-0.53	1.21	0.27	2.08	1.77
Neptunea heros	4.86	7.86	2.47	-0.38	-1.68	-3.35	-1.56	-3.21	-1.78
Neptunea lyrata	4.8	1.26	1.09	-1.9	-3.07	0.27	-1.51	2.14	3.31
Neptunea pribiloffensis	3.56	2.49	2.58	-2.73	-1.82	0	0.9	2.66	1.8
Neptunea ventricosa	2.35	2.79	1.63	-0.13	-0.99	-2.3	-1	-2.32	-1.37
Pyrulofusus deformis	8.79	1.87	1.77	-0.37	-4.17	0.01	-4.27	0.37	4.12
Volutopsius fragilis	12.53	7.38	7.98	-0.07	-5.22	-0.61	-5.33	-0.56	4.49
Cnidaria									
Scyphozoa spp	12.63	5.55	5	-2.65	0.39	3.5	3	6.14	3.05
Chrysaora spp	0.64	28.79	1.21	0.78	0.58	1.37	-0.17	0.63	0.77
Porifera									
Porifera spp	4.93	3.4	1.46	0.47	2.43	3.04	2.37	2.81	0.73
Miscellaneous									
Empty Gastropod Shells	3.21	18.18	6.85	-1.64	-3.05	-1.91	-1.69	-0.42	1.09

Appendix 5: Proc Mixed Models with Contrast Statements. The following models were used to estimate significant differences between aggregates of closed areas and fished areas, between aggregates of pre-closure (1990-1994) and post-closure (1996-2000) years, and between aggregates of pre-closure and post-closure years within each of the closed and fished areas for biomass and abundance of dominant species which had a significant interaction term for area*year.

For Contrasting Biomass:

```
data;
input zone $ year lat long biomass;
biomass= 1000*biomass;
lgbio = log(biomass + 1);
cards;
run;
proc mixed scoring = 50 convh=1e-06;
class zone year;
model lgbio=zone year zone*year/ddfm=satterth;
parms (.25 to 1.0 by .25) (.25 to 1.0 by .25) (1.0 to 50 by 5)/noiter;
repeated/ subject = zone local type = sp(sph) (lat long);
lsmeans zone year zone*year;
contrast 'closed to fished' zone -1 -1 1 1;
contrast 'years 1990-1994 to 1996-2000' year -1 -1 -1 -1 -1 0 1 1 1 1 1;
contrast 'c1 before to c1 after' year -1 -1 -1 -1 -1 0 1 1 1 1 1 zone*year -1 -1 -1 -1 -1
0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
contrast 'c2 before to c2 after' year -1 -1 -1 -1 -1 0 1 1 1 1 1 zone*year 0 0 0 0 0 0 0
0 0 0 0 -1 -1 -1 -1 -1 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
contrast 'f1 before to f1 after' year -1 -1 -1 -1 -1 0 1 1 1 1 1 zone*year 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0;
contrast 'f2 before to f2 after' year -1 -1 -1 -1 -1 0 1 1 1 1 1 zone*year 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 0 1 1 1 1 1;
title 'biomass'; run;
```

For Contrasting Abundance:

```
data;
input zone $ year lat long abundance;
abundance= 1000*abundance;
lgab = log(abundance + 1);
cards; run;
proc mixed scoring = 50 convh=1e-06;
class zone year;
model lgab=zone year zone*year/ddfm=satterth;
parms (.25 to 1.0 by .25) (.25 to 1.0 by .25) (1.0 to 50 by 5)/noiter;
repeated/ subject = zone local type = sp(sph) (lat long);
lsmeans zone year zone*year;
contrast 'closed to fished' zone -1 -1 1 1;
contrast 'years 1990-1994 to 1996-2000' year -1 -1 -1 -1 -1 0 1 1 1 1 1;
contrast 'c1 before to c1 after' year -1 -1 -1 -1 -1 0 1 1 1 1 1 zone*year -1 -1 -1 -1 -1
0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
contrast 'c2 before to c2 after' year -1 -1 -1 -1 -1 0 1 1 1 1 1 zone*year 0 0 0 0 0 0 0
0 0 0 0 -1 -1 -1 -1 -1 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
contrast 'f1 before to f1 after' year -1 -1 -1 -1 -1 0 1 1 1 1 1 zone*year 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0;
contrast 'f2 before to f2 after' year -1 -1 -1 -1 -1 0 1 1 1 1 1 zone*year 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 -1 -1 -1 -1 0 1 1 1 1 1;
title 'abundance';   run;
```

Appendix 6: F values associated with SAS comparisons between closed and fished areas, between pre-closure and post-closure years, and between pre-closure and post-closure years within each area. Areas are described as Closed Area 1 (C1), Closed Area 2 (C2), Fished Area 1 (F1), and Fished Area 2 (F2).

Table 20: F Values

	F-value					
	Closed/Fished	**Before/After**	**C1**	**C2**	**F1**	**F2**
Total Abundance	0.31	0.43	0.06	6.09	0.02	11.53
Total Biomass	2.46	0.35	2.15	7.48	3.4	0.82
Diversity	28.33	16.77	0.36	2.54	20.29	1.99
Evenness	3.98	2.05	0.14	0.44	1.66	1.47
Functional Groups-Abundance						
Piscivores	1.15	6.9	0.03	1.02	11.63	7.47
Benthic Invertebrate Feeders	5.85	0.2	5.53	0.73	4.6	2.8
Functional Groups-Biomass						
Piscivores	2.55	3.58	0.96	0.19	11.72	2.42
Benthic Invertebrate Feeders	1.73	0.9	15.97	1.56	3.49	1.44
Carnivores	4.59	11.28	17.69	0.13	3.07	0.23
Detritivores	15.83	0.12	1.27	2.21	0.03	0.26
Planktivores	37.26	5.05	0.78	2.6	2.01	12.48
Filter-feeding Invertebrates	4.56	3.85	7.43	1.05	2.31	32.27
Paralithodes camtschaticus-abundance	160.33	6.11	7.45	9.67	0.4	0
Paralithodes camtschaticus-biomass	159.01	5.15	4.74	11.65	0.6	0
Dominant Species-Abundance						
Chordata						
Atherestes stomias	6.48	44.23	40.74	23.61	1.83	1.06
Mallotus villosus	2	0.21	8.67	0.31	0	5.35
Pleuronectes quadrituberculatus	2.06	0.07	23.13	0.51	1.5	4.42
Theragra chalcogramma	0.38	6.79	0.16	0.39	11.58	6.57
Arthropoda						
Hyas spp	4.81	29.65	5.16	2.08	17.25	8.38
Pagurus spp	8.03	116.89	37.82	94.3	39.48	0
Chionoecetes bairdi	24.03	74.96	88.52	12.57	0.2	17.35
Chionoecetes opilio	212.32	33.89	12.17	95.87	2.35	6.28
Mollusca						
Buccinum spp	70.72	15.63	0	0.12	5.97	23.15
Volutopsius spp	24.5	1.75	0	0.14	7.05	0.17
Buccinum angulosum	23.96	2.37	0.07	0.05	13.12	0.03
Buccinum polare	34.44	0.46	0	0.06	1.34	6.93
Buccinum scalariforme	68.12	0.38	0	0.01	0.49	0.17
Neptunea heros	2.46	46.42	3.48	1.85	29.87	22.27
Neptunea pribiloffensis	0.19	3.25	0	5.2	3.4	0.19
Volutopsius fragilis	18.49	23	0	0	79.83	0.17

(Table 20 Continued)

Dominant Species-Biomass	Closed/Fished	Before/After	C1	C2	F1	F2
Chordata						
Atherestes stomias	6.23	32.82	26.1	17.46	2.26	0.85
Mallotus villosus	1.7	0	8.62	0.03	0	8.18
Pleuronectes quadrituberculatus	3	0.35	20.7	1.62	2.69	6.69
Theragra chalcogramma	8.54	6.17	0.8	0	15.77	2.91
Hemichordata						
Ascidian spp	7.9	21.24	0.02	0	2.81	49.12
Boltenia spp	68.5	6.15	14.62	2.24	0.46	0.26
Halocynthia spp	6.56	25.09	0.02	0	0.73	73.09
Styela rustica	31.17	40.02	2.27	0.75	23.08	63.67
Echinodermata						
Starfish unidentified	8.43	22.02	0.21	0	34.65	12.9
Ophiuroid unidentified	36.67	13.52	0	0.14	46.34	0
Asterias amurensis	3.93	4.4	9.89	0.79	7.76	11.37
Leptasterias arctica	21.33	26.83	0	0	37.75	16.42
Leptasterias polaris	47.14	7.13	0	0	19.83	0.69
Arthropoda						
Hyas spp	7.49	38.63	3.77	2.16	28.12	12.34
Pagurus spp	0.33	33.49	1.17	18.5	0	37.4
Chionoecetes bairdi	34.84	178.19	158.64	28.6	19.01	22.16
Chionoecetes opilio	289.66	22.99	14.61	122.35	0.01	18.92
Pagurus aleuticus	3.39	122.67	30.13	92.22	56.5	0
Mollusca						
Gastropoda spp	55.17	9.78	0	0.03	6.79	10.15
Buccinum spp	66.68	10.86	0	0.08	6.46	12.39
Volutopsius spp	22.21	1.46	0	0.11	5.72	0.11
Buccinum angulosum	12025	2012	0.03	0.02	13.1	0.01
Buccinum polare	21.77	0	0	0.05	2.52	3.42
Buccinum scalariforme	75.26	0.19	0	0.02	0.23	0.06
Neptunea heros	11.93	47.75	2.62	1.86	34.9	22.11
Neptunea pribiloffensis	0.29	4.41	0	5.66	5.19	0.14
Volutopsius fragilis	7.41	22.55	0	0	69.22	0.85
Cnidaria						
Scyphozoa spp	21.72	0.12	1.18	6.03	0.01	7.11
Miscellaneous						
Empty Gastropod Shells	6.98	163.33	18.42	8.6	39.51	134.06

Appendix 7: List of Species. Scientific names, common names, occurrence (denoted as "O"), and dominance (denoted as "X") are shown below for the Nearshore Bristol Bay Closure Area (C1), the Bristol Bay Red King Crab Savings Area (C2), Fished Area 1 (F1) and Fished Area 2 (F2).

Table 21: List of Species

Scientific Name	Common Name	Dominance			
Chordata		C1	C2	F1	F2
	fish eggs unidentified	O			
Rajidae unidentified	skate unidentified	O	O	O	O
	skate egg case unidentified			O	
Bathyraja spp			O	O	
Raja binoculata	big skate			O	
Bathyraja interrupta	Bering skate			O	O
Bathyraja tanatretzi	mud skate			O	
Bathyraja parmifera	Alaska skate	O	O	O	O
Bathyraja aleutica	Aleutian skate		O	O	
Atheresthes stomias	arrowtooth flounder	O	X	O	O
Atheresthes evermanni	Kamchatka flounder		O	O	
Reinhardtius hippoglossoides	greenland turbot			O	O
Hippoglossus stenolepis	Pacific halibut	O	O	O	O
Hippoglossus elassodon	flathead sole	X	X	X	O
Hippoglossoides robustus	Bering flounder				O
Glyptocephalus zachirus	rex sole	O	O	O	
Limanda aspera	yellowfin sole	X	X	X	X
Limanda proboscidea	longhead dab	O	O		O
Limanda sakhalinensis	Sakhalin sole				O
Platichthys stellatus	starry flounder	O			
Lepidopsetta sp. cf.bilineata	northern rock sole	X	X	X	X
Isopsetta isolepis	butter sole	O	O		
Pleuronectes quadrituberculatus	Alaska plaice	X	X	X	X
Agonidae spp	poacher unident.				O
Sarritor leptorhynchus	longnose poacher			O	
Sarritor frenatus	sawback poacher			O	
Podothecus acipenserinus	sturgeon poacher	X	X	O	X
Aspidophoroides bartoni	Aleutian alligatorfish	O	O	O	
Occella dodecaedron	Bering poacher			O	
Ammodytes hexapterus	Pacific sand lance	O			
Bathymaster signatus	searcher			O	
Clupea pallasi	Pacific herring	O	O	O	O
Cottidae	sculpin unidentified	O			
Gymnocanthus spp		O			
Gymnocanthus pistilliger	threaded sculpin	O			
Hemilepidotus spp	Irish lord	O			
Hemilepidotus jordani	yellow Irish lord	O	O	O	
Hemilepidotus papilio	butterfly sculpin				O
Triglops spp		O			O
Triglops scepticus	spectacled sculpin			O	

(Table 21 Continued)

Scientific Name	**Common Name**	**Dominance**			
Triglops pingeli	ribbed sculpin	O	O		O
Myoxocephalus verrucosus	warty sculpin				O
Myoxocephalus polyacanthocephalus	great sculpin	O	O	O	O
Myoxocephalus jaok	plain sculpin	O	O	O	O
Myoxocephalus spp		O			O
Dasycottus setiger	spinyhead sculpin		O	O	
Nautichthys pribilovius	eyeshade sculpin	O			
Hemitripterus bolini	bigmouth sculpin	O		O	
Icelus spiniger	thorny sculpin				O
Icelus spatula	spatulate sculpin			O	O
Icelus spp		O	O	O	O
Trichodon trichodon	Pacific sandfish	O			
Gadus macrocephalus	Pacific cod	X	X	O	X
Boreogadus saida	arctic cod				O
Theragra chalcogramma	walleye pollock	X	X	X	X
Liparidinae	snailfish unidentified			O	O
Liparis spp					O
Liparis gibbus	ducky snailfish				O
Careproctus spp				O	
Thaleichthys pacificus	eulachon	O	O	O	
Mallotus villosus	capelin	O	O	O	X
Osmerus mordax	rainbow smelt	O			
Oncorhynchus tshawytscha	chinook salmon			O	
Lumpenus maculatus	daubed shanny			O	
Lumpenus sagitta	snake prickleback			O	O
Lycodes raridens	marbled eelpout			O	O
Lycodes palearis	wattled eelpout		O	O	O
Lycodes brevipes	shortfin eelpout			O	O
Hemichordata					
Ascidian unidentified	tunicate unidentified	O	O	O	X
Thaliacea unidentified	salps unidentified				O
Styela rustica	sea potato	O		X	X
Boltenia ovifera	sea onion	X	O	O	O
Halocynthia spp	unidentified sea peaches	O		X	X
	compound ascidian unidentified	O			O
Aplidium spp		O	O		O
Synoicum spp					O
Molgula grifithsii	sea grape				O
Echinodermata					
Ophiuroid spp	Sea star unidentified			X	X
Evasterias spp		O			
Evasterias echinosoma	giant sea star	X	O		O
Lethasterias nanimensis		O	O	O	O
Henricia spp					O

(Table 21 Continued)

Scientific Name	**Common Name**	**Dominance**			
Leptasterias polaris	knobby six-rayed sea star			X	O
Leptasterias arctica	arctic sea star			X	O
Leptasterias spp		O		O	O
Pteraster spp				O	
Pteraster obscurus				O	
Asterias spp		O		O	
Asterias amurensis	purple-orange seastar	X	X	X	X
	sea urchin unidentified			O	
Stongylocentrotus droebachiensis	green sea urchin			O	
	sand dollar unidentified	O	O		
	brittlestarfish unidentified			X	
Gorgonocephalus eucnemis	basket star	O	X	X	X
Ophiura spp				O	
Ophiura sarsi	notched brittlestar	O		X	
Ophiopholis aculeata			O		
Holothuroidea unidentified	cucumber unidentified		O		
Cucumaria spp		O	O		
Cucumaria fallax		O	O		
Arthropoda					
Balanus spp					O
Balanus evermanni	giant barnacle		O		
Balanus rostratus	beaked barnacle	O	O		
	shrimp unident.	O			
Pandalidae	pandalid shrimp unidentified			O	
Pandalus borealis	northern shrimp	O	O	O	O
Pandalus goniurus	humpy shrimp	O	O	O	O
Crangon spp		O		O	
Crangon communis	twospine crangon			O	
Crangon dalli	ridged crangon	O			
Argis spp				O	O
Argis dentata	arctic argid			O	O
Sclerocrangon spp		O			
Argis lar	kuro argid		O	O	O
Cancer magister	Dungeness crab		O		
Cancer oregonensis	Oregon rock crab	O	O		
Oregonia gracilis	graceful decorator crab	O	O	O	
Chionoecetes bairdi	tanner crab	O	X	X	O
Hyas coarctatus	circumboreal toad crab	O	O	X	O
Hyas lyratus	Pacific lyre crab	O	O	X	
Chionoecetes opilio	narrow snow crab	O	O	X	X
Chionoecetes hybrid	hybrid tanner crab			O	O
Paguridae	hermit crab unidentified	O	X	X	X
Pagurus spp	hermit crab unidentified		X	O	O
Pagurus brandti	sponge hermit crab		O		
Pagurus aleuticus	Aleutian hermit crab	O	X	X	

(Table 21 Continued)

Scientific Name	Common Name	Dominance			
Labidochirus splendescens	splendid hermit crab	O	O	O	O
Pagurus confragosus	knobbyhand hermit crab		O	O	
Pagurus trigonocheirus	fuzzy hermit crab			O	
Pagurus ochotensis	Alaskan hermit crab	O	O		O
Pagurus rathbuni	longfinger hermit crab			O	
Elassochirus tenuimanus	widehand hermit crab			O	
Pagurus capillatus	hairy hermit crab	O	O	O	
Elassochirus cavimanus	purple hermit crab			O	
Paralithodes camtschaticus	red king crab	X	X		O
Paralithodes platypus	blue king crab				O
Paralomis spp		O			
Erimacrus isenbeckii	horsehair crab	O	O	O	O
Hyas spp	unidentified spider crabs	O	O	X	O
Annelida					
Polychaeta	polychaete worm unidentified				O
Polynoidae	scale worm unidentified		O		
Eunoe spp				O	
Eunoe nodosa	giant scale worm		O	O	O
Eunoe depressa	depressed scale worm		O	O	
Mollusca					
	gastropod eggs	O	O	O	O
	nudibranch unidentified		O	O	O
Tritonia spp					O
Tritonia diomedea	rosy tritonia			O	O
Naticidae	gastropod unidentified	O	O	X	O
Natica spp			O	O	
Natica aleutica		O			
Polinices spp				O	O
Crepidula spp	slipper shell		O		
Crepidula grandis	great slippersnail			O	
Colus spp				O	
Colus hypolispus	oblique whelk			O	
Colus spitzbergensis	thick-ribbed whelk			O	
Volutopsius spp	unidentified volute whelks			X	O
Pyrulofusus deformis	warped whelk		O	X	
Volutopsius fragilis	fragile whelk			X	
Volutopsius castaneus	volute whelk			O	
Pyrulofusus melonis				O	
Volutopsius stefanssoni	shouldered whelk				
Beringius spp			O	O	
Beringius kennicottii			O		
Beringius beringii			O		
Neptunea spp	neptune whelks		O	X	
Neptunea pribiloffensis	Pribilof whelk		X	X	
Neptunea borealis				O	O
Neptunea lyrata	lyre whelk	O	X	X	O

(Table 21 Continued)

Scientific Name	**Common Name**	**Dominance**			
Neptunea ventricosa	fat whelk	O	X	X	X
Neptunea heros	northern neptune	O	O	X	X
Neptunea magna	helmet whelk			O	O
Plicifusus kroyeri			O	O	
Aforia circinata	keeled aforia			O	
Fusitriton oregonensis	Oregon triton	O	X	O	
Fusitriton spp				O	
Buccinum spp	buccinum whelk			X	X
Buccinum angulosum	angulate buccinum	O		X	
Buccinum plectrum	sinous whelk			O	O
Buccinum scalariforme	ladder whelk			O	X
Buccinum polare	polar whelk			X	X
Buccinum solenum				O	
Velutina velutina	smooth lamellaria	O			
Pelecypoda unidentified	bivalve unidentified	O	O		O
Mytilidae	mussel unidentified	O			O
Modiolus modiolus	northern horsemussel	O			
Mytilus spp		O			
Mytilus edulis	blue mussel	O	O		
Chlamys rubida	reddish scallop			O	
Patinopecten caurinus	weathervane scallop		O	O	
Yoldia spp			O	O	
Musculus spp					O
Musculus discors	discordant mussel			O	O
Cyclocardia crebicostata	many-rib cyclocardia			O	
Kellia laperousii	La Perouse kellyclam				
Clinocardium spp				O	
	cockle unidentified				O
Clinocardium nuttallii	Nuttall cockle				
Mactromeris spp		O	O		
Mactromeris polynyma	arctic surfclam	O	O		
Tellina lutea	Alaskan great-tellin	O			
Macoma spp		O			
Serripes groenlandicus	Greenland cockle		O		
Pododesmus macroschisma	Alaska falsejingle	O	O		
Pododesmus spp		O			
	octopus unidentified			O	
Rossia pacifica	eastern Pacific bobtail	O			
Bryozoa					
	bryozoan unidentified	O		O	O
Eucratea loricata	feathery bryozoan				O
Flustra serrulata	leafy bryozoan	O			
Cellepora ventricosa	coral bryozoan		O		
Sipuncula					
Spiuncula	sipunculid worm unidentified		O		

(Table 21 Continued)

Scientific Name	Common Name	Dominance			
Cnidaria					
Scyphozoa	jellyfish unidentified	X	X	X	X
Chrysaora spp	sea nettles	X	O	O	O
Gersemia spp		O		O	O
Gersemia rubiformis	sea raspberry	O			O
Actinaria	sea anemone unidentified	O	O	O	O
Metridium spp			O		
Tealia crassicornis				O	O
Liponemis brevicornis			O	O	
Schleractinia unidentified	stony coral unidentified			O	
Porifera					
Porifera	sponge unidentified	X	X	O	O
Aphrocallistes vastus	clay pipe sponge		O		
Halichondria panicea	barrel sponge	O	O		
Miscellaneous					
	invertebrate unidentified	O	O	O	
	empty bivalve shells	O	O	O	O
	empty gastropod shells	O	X	X	X

Appendix 8: Total Abundance, Total Biomass, Diversity, Evenness and CPUE for Each Haul. Year, trawl number, latitude, longitude, study area, total abundance (#), total biomass (Kg), diversity, evenness, and CPUE (catch per unit effort – number/nm^2) are listed below for all hauls in all four areas (C1, C2, F1, F2) and for all years (1990-2000).

Table 22: Total Parameters and CPUE for Each Haul

Year	Trawl	Latitude	Longitude	Area	Abundance	Biomass	Diversity	Evenness	CPUE
1990	37-12	57.673	-160.263	C1	10363	1183.9	1.1	0.33	44.2
1990	37-13	57.347	-160.26	C1	3979	703.5	1.78	0.48	45.2
1990	37-15	56.949	-160.297	C1	4960	1433.2	1.61	0.45	47
1990	37-16	56.668	-161.515	C1	5654	1601.5	2.08	0.6	46.9
1990	37-17	56.996	-161.55	C1	6070	1347.3	1.76	0.55	45.5
1990	37-18	57.34	-161.528	C1	8548	1809.9	1.96	0.58	46.4
1990	37-19	57.668	-161.496	C1	8763	1301.7	1.63	0.45	43.7
1990	78-11	56.669	-160.368	C1	7887	1297.3	1.47	0.43	48.5
1990	78-14	56.675	-160.999	C1	5705	1642	1.59	0.47	45.3
1990	78-15	57.013	-160.948	C1	4089	925.3	1.72	0.53	45.5
1990	78-16	57.392	-160.932	C1	1129	273.8	1.57	0.48	53
1991	78-17	57.639	-160.267	C1	4644	1406.2	1.18	0.32	53
1991	78-18	57.382	-160.2	C1	2605	779.5	1.24	0.37	43.6
1991	78-19	57.02	-160.338	C1	3546	1732.8	1.43	0.4	48.3
1991	78-20	56.681	-160.426	C1	3899	1061.9	1.63	0.48	48.7
1991	78-22	56.717	-160.992	C1	7117	1977.6	1.16	0.34	41.9
1991	78-23	57.018	-160.949	C1	2050	780.2	1.48	0.43	40.4
1991	78-24	57.361	-160.94	C1	1392	450.8	1.33	0.38	46.9
1991	78-31	57.28	-161.54	C1	3975	1447.1	1.69	0.48	44.8
1991	78-32	56.988	-161.562	C1	1823	631	1.34	0.4	51.8
1991	78-33	56.652	-161.583	C1	3865	1297.3	1.55	0.48	44.4
1992	37-6	56.988	-160.334	C1	2550	592.8	1.46	0.42	47.2
1992	37-7	57.323	-160.3	C1	3077	836	1.56	0.45	47.2
1992	37-8	57.657	-160.267	C1	5929	966.2	1.05	0.32	43.2
1992	37-14	57.338	-161.535	C1	17576	3601.9	0.79	0.26	46.9
1992	37-15	57.011	-161.57	C1	7786	1560.3	0.95	0.31	47.8
1992	37-16	56.677	-161.585	C1	3549	1828	1.78	0.55	43.1
1992	87-11	56.671	-160.987	C1	5085	1113.7	1.17	0.35	51.8
1992	87-12	57.007	-160.945	C1	2166	550.9	1.33	0.44	49.4
1992	87-13	57.329	-160.947	C1	1953	536	1.35	0.46	48.6
1992	87-14	57.669	-160.888	C1	11826	2254.3	1.31	0.41	49
1993	88-8	56.66	-160.365	C1	7879	2104.8	1.55	0.44	45.8
1993	88-9	56.993	-160.332	C1	4624	1989.1	1.5	0.46	46.4
1993	88-10	57.326	-160.307	C1	7873	1535.1	1.18	0.33	49.8
1993	88-11	57.661	-160.267	C1	10666	1932.4	1.33	0.39	43.2
1993	88-17	57.652	-161.461	C1	10690	1877.8	1.31	0.42	48.7
1993	88-18	57.338	-161.537	C1	6195	1810	1.68	0.48	52.4
1993	88-19	57.004	-161.564	C1	9537	2381.4	1.37	0.46	49.1
1993	88-20	56.684	-161.561	C1	4917	3778.4	2.06	0.64	46.3
1993	89-10	57.335	-160.93	C1	2880	1465	1.67	0.5	51.8
1993	89-11	57.012	-160.953	C1	4983	1002.5	1.25	0.37	56.2

(Table 22 Continued)

Year	Trawl	Latitude	Longitude	Area	Abundance	Biomass	Diversity	Evenness	CPUE
1993	89-12	56.678	-160.973	C1	7709	2971.1	1.56	0.5	53.7
1994	88-10	57.341	-160.923	C1	5685	2310.1	1.53	0.48	47.3
1994	88-11	57.016	-160.903	C1	12643	6340.1	1.23	0.42	46
1994	88-12	56.671	-160.943	C1	6185	4992.1	1.49	0.44	48.8
1994	89-10	57.665	-160.269	C1	12169	2707.8	1.23	0.4	45.5
1994	89-11	57.323	-160.305	C1	6722	1638	1.36	0.41	47.9
1994	89-12	56.992	-160.336	C1	4318	1360.2	1.22	0.42	44.9
1994	89-13	56.663	-160.372	C1	4270	1680.1	1.75	0.52	43.8
1994	89-16	56.672	-161.56	C1	3527	2580	1.85	0.62	42.8
1994	89-17	56.997	-161.56	C1	24541	2840	0.74	0.26	44.7
1994	89-18	57.339	-161.521	C1	10103	2400.2	1.42	0.44	44.7
1994	89-19	57.649	-161.484	C1	11228	2796.2	1.42	0.44	44.4
1995	88-11	56.664	-160.974	C1	5624	1684	1.28	0.38	42.7
1995	88-12	56.992	-160.951	C1	2681	620.3	1.2	0.38	43.9
1995	88-13	57.332	-160.938	C1	1391	491.7	1.22	0.39	41.9
1995	88-14	57.648	-160.877	C1	1773	1098	1.93	0.58	46
1995	89-8	57.339	-160.304	C1	6610	1293.3	1.23	0.36	48.5
1995	89-9	57.005	-160.332	C1	10908	2100.6	1.22	0.36	50.5
1995	89-10	56.671	-160.362	C1	5711	1480	1.24	0.37	56.3
1995	89-13	56.681	-161.608	C1	919	1020	2.05	0.71	24.6
1995	89-14	56.995	-161.573	C1	4817	1640	1.51	0.51	47.1
1995	89-15	57.322	-161.538	C1	15136	2850	1.25	0.4	42.6
1995	89-16	57.66	-161.496	C1	9466	2340	1.53	0.5	43.5
1996	88-8	57.341	-160.306	C1	3470	987.2	1.59	0.43	48.1
1996	88-9	56.973	-160.318	C1	6006	1470	1.31	0.38	45.9
1996	88-10	56.667	-160.35	C1	4423	1490	1.82	0.52	53
1996	88-13	57.001	-161.537	C1	2385	1210	1.57	0.56	42.5
1996	88-14	57.318	-161.653	C1	11714	2980	1.13	0.34	44.2
1996	88-15	57.651	-161.551	C1	3449	1700	1.62	0.48	44.6
1996	89-11	56.658	-160.981	C1	1727	950	1.91	0.62	49.8
1996	89-12	56.989	-160.929	C1	2317	1250	1.69	0.57	47.4
1996	89-13	57.323	-160.932	C1	3580	1750	1.6	0.54	46.7
1996	89-14	57.655	-160.886	C1	1935	680	1.69	0.51	46.6
1997	88-8	57.332	-160.296	C1	8113	2319.6	1.5	0.43	48.7
1997	88-9	56.999	-160.324	C1	5451	1634.8	1.49	0.44	51.7
1997	88-13	56.994	-161.566	C1	4867	1500.1	1.13	0.36	50.3
1997	88-14	57.32	-161.537	C1	6734	2080	1.45	0.44	41
1997	89-10	56.665	-160.364	C1	5711	1700	1.77	0.48	42.7
1997	89-11	56.667	-160.972	C1	5286	2210	1.63	0.49	41.2
1997	89-12	56.99	-160.95	C1	2763	1160	1.6	0.49	41.4
1997	89-13	57.323	-160.935	C1	5894	1870	1.61	0.47	42.2
1997	89-14	57.661	-160.88	C1	7557	1777	1.54	0.47	46.6
1998	88-14	56.981	-160.948	C1	3711	1150	1.35	0.39	43
1998	88-15	57.327	-160.937	C1	3775	1100	1.67	0.49	42.9
1998	88-16	57.656	-160.889	C1	5116	1260	1.61	0.43	42.6

(Table 22 Continued)

Year	Trawl	Latitude	Longitude	Area	Abundance	Biomass	Diversity	Evenness	CPUE
1998	89-6	57.34	-160.303	C1	5003	1283.8	1.45	0.4	51.9
1998	89-7	57.009	-160.334	C1	8527	2073.3	1.47	0.42	49.4
1998	89-8	56.676	-160.369	C1	7653	1801.9	1.65	0.45	49.5
1998	89-10	56.66	-161.584	C1	6405	6934.9	1.86	0.55	48.2
1998	89-11	56.991	-161.567	C1	6296	1751.3	1.2	0.37	48.4
1998	89-12	57.323	-161.536	C1	4978	1551.9	1.64	0.48	46.4
1998	89-13	57.655	-161.496	C1	5549	1486.9	1.41	0.42	46.3
1999	88-13	57.34	-160.928	C1	7590	2288	0.97	0.28	47.1
1999	88-14	57.018	-160.93	C1	5662	1690	0.91	0.25	47.1
1999	88-15	56.66	-161.004	C1	7039	1714	1.23	0.35	48
1999	89-2	57.327	-160.305	C1	5841	1594.3	1.54	0.42	50.3
1999	89-3	57.015	-160.338	C1	10035	2314	0.9	0.26	52.9
1999	89-4	56.678	-160.363	C1	11460	3170	1.06	0.31	48.4
1999	89-5	57.658	-160.265	C1	2635	622.9	1.81	0.49	49.8
1999	89-13	57.341	-161.538	C1	6406	1660.1	1.22	0.35	48.7
1999	89-14	57.009	-161.568	C1	7982	2268	0.89	0.27	49.8
1999	89-15	56.669	-161.59	C1	10773	7136	0.93	0.29	45.1
2000	88-10	56.668	-160.372	C1	15342	1954	1.29	0.33	46.5
2000	88-11	56.982	-160.346	C1	4619	950.3	1.4	0.37	46
2000	88-12	57.325	-160.297	C1	5314	1140	1.85	0.47	45.4
2000	88-21	57.662	-161.501	C1	6131	1400	1.84	0.53	45.3
2000	88-22	57.334	-161.54	C1	4511	1041.3	1.78	0.49	47.3
2000	88-23	57.005	-161.561	C1	6827	1730.6	1.62	0.47	46.7
2000	88-24	56.69	-161.541	C1	2042	3860	1.96	0.55	23
2000	89-11	56.661	-160.988	C1	4692	1380	1.41	0.4	42.3
2000	89-12	56.992	-160.952	C1	9018	1960	1.31	0.38	42.5
2000	89-13	57.32	-160.931	C1	2814	800	1.7	0.48	43.8
2000	89-14	57.651	-160.879	C1	1686	2425	1.44	0.44	24.5
1990	37-28	56.669	-162.766	C2	5328	1169.1	1.61	0.48	43.7
1990	37-30	56.328	-162.803	C2	2960	1057.9	1.72	0.51	46.6
1990	37-31	56.009	-162.814	C2	3782	1891.5	2.25	0.72	47.8
1990	78-24	56.995	-162.163	C2	6089	1383.3	1.6	0.47	47.5
1990	78-25	56.69	-162.225	C2	6148	1587.7	1.31	0.4	35.6
1990	78-27	56.342	-162.227	C2	5706	1751	1.59	0.47	45.6
1990	78-28	56.005	-162.274	C2	5663	2023.2	1.94	0.58	44.7
1990	78-31	56.013	-163.405	C2	1606	1084.1	2.51	0.72	47.8
1990	78-32	56.334	-163.405	C2	2262	998	1.87	0.58	47.5
1990	78-33	56.676	-163.401	C2	3676	1274.7	1.5	0.46	35.6
1990	78-35	56.727	-163.817	C2	4342	1537.4	1.3	0.38	45.6
1990	78-36	56.995	-163.554	C2	4579	1799.2	1.89	0.54	47.4
1991	37-4	56.684	-162.793	C2	5091	1220.1	1.62	0.48	50.6
1991	37-5	56.313	-162.807	C2	6417	1601.1	1.08	0.36	51.6
1991	37-6	56.02	-162.798	C2	3484	1251.9	1.99	0.63	55.3
1991	78-35	56.064	-162.215	C2	4495	1697.4	1.67	0.5	47.8
1991	78-36	56.374	-162.198	C2	5468	1909.6	1.54	0.46	45.4

(Table 22 Continued)

Year	Trawl	Latitude	Longitude	Area	Abundance	Biomass	Diversity	Evenness	CPUE
1991	78-37	56.692	-162.173	C2	3246	875.3	1.37	0.43	46.4
1991	78-54	56.721	-163.362	C2	2712	662.1	1.9	0.54	43.5
1991	78-55	56.373	-163.394	C2	1349	527.6	2.03	0.65	46.4
1991	78-56	56.044	-163.396	C2	1733	718	1.99	0.57	46.2
1992	37-18	56.344	-162.199	C2	1980	830.1	1.65	0.52	32.9
1992	37-19	56.015	-162.232	C2	449	659.2	1.57	0.53	45.9
1992	37-22	56.323	-162.801	C2	534	260.4	1.68	0.55	50.1
1992	37-23	56.662	-162.785	C2	1170	507	1.55	0.5	49.8
1992	37-24	56.993	-162.789	C2	4357	840	1.5	0.47	47.5
1992	87-21	56.99	-162.165	C2	14902	2494.8	1.21	0.38	30.2
1992	87-22	56.659	-162.181	C2	3281	2267.9	1.72	0.61	31.1
1992	87-26	56.344	-163.38	C2	4296	1914.3	1.55	0.5	49
1992	87-27	56.662	-163.384	C2	2912	1551.2	1.76	0.59	53.5
1992	87-28	56.998	-163.384	C2	4318	1356.1	1.35	0.44	47.3
1993	88-24	56.313	-162.817	C2	6899	2771.6	1.14	0.39	52.8
1993	88-25	56.647	-162.784	C2	3735	1519.5	1.31	0.42	49.4
1993	88-26	56.982	-162.803	C2	13652	2757.8	1.05	0.36	45.6
1993	88-39	56.687	-163.994	C2	3835	1601.2	1.62	0.48	51.2
1993	89-15	56.312	-162.202	C2	3963	2290.6	1.4	0.45	56.6
1993	89-16	56.637	-162.184	C2	9006	2898.5	1.28	0.41	60.1
1993	89-17	56.992	-162.157	C2	5726	2485.7	1.22	0.39	60.5
1993	89-30	56.675	-163.383	C2	5215	2045.7	1.55	0.5	56
1993	89-34	56.351	-163.402	C2	3001	1456.1	0.89	0.29	25.3
1993	89-35	56.013	-163.403	C2	1494	1628.4	2.2	0.71	52.8
1994	88-14	56.316	-162.238	C2	2897	1440.3	1.64	0.53	45.7
1994	88-15	56.645	-162.167	C2	4703	1670	1.33	0.44	49.6
1994	88-16	56.997	-162.151	C2	10580	2144	1.4	0.43	45.8
1994	88-27	56.991	-163.401	C2	855	2910.2	1.43	0.43	45.4
1994	88-28	56.684	-163.396	C2	5047	1741.8	1.92	0.57	45
1994	88-30	56.324	-163.399	C2	2126	794.8	1.96	0.59	46.5
1994	88-31	56.019	-163.394	C2	1346	2008.2	2.23	0.67	46
1994	89-28	56.987	-162.806	C2	9255	1826	1.66	0.54	47.6
1994	89-29	56.679	-162.78	C2	9135	2857.9	1.61	0.52	44.2
1994	89-30	56.344	-162.804	C2	2843	1834.1	1.6	0.58	50.6
1994	89-31	56.01	-162.817	C2	2658	1230.1	1.77	0.64	47.7
1994	89-41	56.674	-163.993	C2	7843	2894	1.16	0.4	47
1995	88-22	56.995	-162.18	C2	6447	1450	1.48	0.47	45.3
1995	88-23	56.663	-162.185	C2	3119	1940	1.67	0.53	42.3
1995	88-24	56.326	-162.205	C2	4223	2808	1.3	0.43	44.8
1995	88-29	56.309	-163.415	C2	1195	499.1	1.66	0.55	43.8
1995	88-30	56.657	-163.398	C2	1747	1052	1.88	0.6	50.8
1995	89-26	56.66	-162.776	C2	6324	1247.5	1.52	0.46	48.4
1995	89-27	56.345	-162.802	C2	3557	1110	1.73	0.54	51.2
1996	88-23	56.98	-162.775	C2	7717	1242	1.34	0.39	52
1996	88-24	56.652	-162.796	C2	6587	1709	1.5	0.49	45.1

(Table 22 Continued)

Year	Trawl	Latitude	Longitude	Area	Abundance	Biomass	Diversity	Evenness	CPUE
1996	88-25	56.331	-162.801	C2	2403	730.2	1.72	0.54	44.6
1996	89-22	56.675	-162.189	C2	3859	1840	1.74	0.56	46
1996	89-23	56.339	-162.21	C2	6359	4070	1.79	0.58	46.9
1996	89-24	56.009	-162.231	C2	5682	3100	1.46	0.48	30.9
1996	89-29	56.325	-163.402	C2	4359	1400	1.91	0.61	45.5
1996	89-30	56.652	-163.382	C2	3472	961.6	1.75	0.52	46.6
1996	89-31	56.991	-163.385	C2	5808	1040	1.75	0.52	42.7
1997	88-23	56.975	-162.763	C2	8889	2143	1.01	0.31	48.6
1997	88-24	56.65	-162.786	C2	5156	3300	1.66	0.52	48.5
1997	88-25	56.336	-162.786	C2	10381	3650	1.12	0.37	48.5
1997	88-26	56.006	-162.824	C2	5791	2400	1.86	0.56	55.7
1997	88-29	56	-163.956	C2	3103	2270	2.57	0.73	46.8
1997	89-22	56.678	-162.186	C2	6623	2435	1.46	0.45	46
1997	89-23	56.34	-162.205	C2	3743	4140	1.32	0.45	25.5
1997	89-24	56.009	-162.239	C2	6538	1826.6	1.69	0.52	45.3
1997	89-30	56.346	-163.402	C2	1478	647.4	1.69	0.54	46.5
1997	89-31	56.659	-163.387	C2	3564	1820	2.07	0.66	47.9
1997	89-32	56.989	-163.381	C2	11482	1880	1.45	0.46	42.7
1998	88-24	56.677	-162.185	C2	3922	1860	1.48	0.46	44.1
1998	88-25	56.323	-162.201	C2	5360	2630	1.52	0.44	43.7
1998	88-31	56.322	-163.392	C2	5452	1300	1.94	0.57	46.7
1998	88-32	56.674	-163.408	C2	4500	1240	1.88	0.56	45.9
1998	88-33	56.999	-163.387	C2	10169	2880	1.45	0.43	45.8
1998	89-22	56.677	-162.786	C2	7495	2139.9	1.35	0.41	48.8
1998	89-23	56.344	-162.804	C2	4877	1717.9	1.56	0.48	51.7
1998	89-24	56.009	-162.816	C2	3742	1549.9	1.55	0.49	52.6
1998	89-28	56.353	-163.997	C2	4456	1669.9	2.07	0.6	57.9
1998	89-29	56.64	-163.982	C2	3600	987.9	1.87	0.57	60.6
1998	89-30	56.987	-163.968	C2	9404	4428.8	1.4	0.41	50.3
1999	88-18	56.337	-162.223	C2	5537	5027	1.6	0.51	42.6
1999	88-19	56.653	-162.149	C2	3734	1912	1.33	0.38	47.1
1999	88-33	56.664	-163.384	C2	3407	1720	2.44	0.72	46.9
1999	88-34	56.336	-163.355	C2	1530	499	2.48	0.68	18.2
1999	88-35	56.018	-163.388	C2	3667	1684	2.71	0.72	47.3
1999	89-19	56.322	-162.798	C2	3853	2052	1.68	0.53	48.6
1999	89-2	56.658	-162.781	C2	3593	1114	1.81	0.55	52.7
1999	89-21	56.989	-162.785	C2	5335	1618	1.55	0.49	48.7
1999	89-35	56.679	-163.985	C2	11323	3252	1.53	0.48	51.1
1999	89-36	56.346	-163.978	C2	2127	780.5	2.26	0.65	52.8
1999	89-37	56.012	-163.98	C2	4219	2770	2.24	0.69	51.1
2000	88-38	56.327	-162.639	C2	3566	1870	1.69	0.48	35.5
2000	88-39	56.652	-162.772	C2	4634	1560	1.96	0.55	49
2000	88-40	56.979	-162.786	C2	9151	1690	1.15	0.34	48.4
2000	88-61	56.359	-163.964	C2	3032	1770	1.7	0.5	48.6
2000	88-62	56.655	-163.928	C2	3670	1956	1.8	0.54	46.4

(Table 22 Continued)

Year	Trawl	Latitude	Longitude	Area	Abundance	Biomass	Diversity	Evenness	CPUE
2000	88-63	56.99	-163.88	C2	3994	1530	1.85	0.56	48.5
2000	89-26	56.68	-162.174	C2	1866	840	1.65	0.53	32.2
2000	89-27	56.343	-162.198	C2	2304	3670	1.61	0.49	22
2000	89-28	56.002	-162.252	C2	5892	5170	0.77	0.29	44.1
2000	89-29	56	-162.816	C2	4508	2870	1.41	0.47	46.2
2000	89-31	56.011	-163.398	C2	2608	1775.1	2.37	0.64	47.3
2000	89-41	56.32	-163.403	C2	2865	2050	1.26	0.4	47.8
2000	89-42	56.657	-163.381	C2	2488	1740	1.86	0.62	47.5
2000	89-43	56.987	-163.386	C2	2784	709.7	1.65	0.5	44.9
1990	37-51	57.332	-165.236	F1	5800	1528.7	2.31	0.7	42.2
1990	37-52	57.012	-165.2	F1	7846	2313.3	2.55	0.73	44.4
1990	37-53	56.681	-165.233	F1	4789	1332	2.55	0.68	45.3
1990	37-65	56.658	-166.436	F1	2241	1320.1	2.14	0.67	30.7
1990	37-66	56.997	-166.437	F1	5438	2154.6	1.3	0.43	46.1
1990	37-67	57.322	-166.494	F1	8643	1719	1.84	0.6	40.9
1990	78-64	56.657	-165.819	F1	7215	1363.5	2.31	0.69	49.8
1990	78-65	56.995	-165.805	F1	4808	1271	2.45	0.69	42.2
1990	78-66	57.346	-165.828	F1	5638	1388.1	2.29	0.63	48.5
1991	37-47	57.35	-165.23	F1	5362	1791.7	2	0.58	48.5
1991	37-48	57.015	-165.219	F1	3456	1519.6	2.16	0.63	48.9
1991	37-49	56.673	-165.221	F1	4553	1837.3	2.17	0.62	49
1991	37-61	56.654	-166.462	F1	542	3320.4	1.98	0.61	47.3
1991	37-62	56.986	-166.477	F1	11564	2245.3	1.89	0.55	50.3
1991	37-63	57.336	-166.486	F1	5888	1850.6	2.21	0.69	45.8
1991	78-68	57.335	-165.867	F1	4991	2000.3	1.94	0.69	54.2
1991	78-69	56.994	-165.851	F1	3416	1533.2	2.23	0.68	58
1991	78-70	56.66	-165.855	F1	3520	2032.2	2.12	0.73	56.8
1992	37-56	56.991	-165.217	F1	2159	899.46	1.48	0.47	46.8
1992	37-57	57.322	-165.235	F1	5766	1542.29	1.47	0.44	45.7
1992	37-71	57.348	-166.493	F1	5750	2254.39	1.31	0.41	48.7
1992	37-72	56.994	-166.445	F1	4136	1360.8	1.29	0.42	33.5
1992	37-73	56.678	-166.442	F1	1339	589.14	2.06	0.65	37.7
1992	87-46	56.66	-165.217	F1	3218	870.8	1.7	0.52	48
1992	87-47	56.674	-165.84	F1	642	348	1.66	0.56	47.1
1992	87-52	56.989	-165.851	F1	6329	2894	1.88	0.54	44.6
1992	87-53	57.309	-165.863	F1	8638	2653.7	1.63	0.48	46.6
1993	88-50	56.657	-165.222	F1	2671	1029.5	2.32	0.66	54.6
1993	88-51	56.992	-165.221	F1	4099	1737.3	1.64	0.48	50.5
1993	88-52	57.328	-165.235	F1	5968	1959.4	1.52	0.44	55.5
1993	88-66	57.347	-166.48	F1	2819	1272	1.86	0.56	49.1
1993	88-67	57.027	-166.435	F1	7095	2136.5	2.12	0.61	49.8
1993	88-68	56.688	-166.432	F1	1721	671.8	2.28	0.67	53.8
1993	89-59	57.35	-165.879	F1	14979	3475.1	1.83	0.54	58
1993	89-60	57.023	-165.853	F1	4964	1846.2	2.52	0.72	55.5
1993	89-61	56.66	-165.799	F1	4176	2834.9	1.43	0.43	32.4

(Table 22 Continued)

Year	Trawl	Latitude	Longitude	Area	Abundance	Biomass	Diversity	Evenness	CPUE
1994	88-55	57.32	-165.835	F1	3871	1199.2	2.38	0.74	45.4
1994	88-56	57.022	-165.838	F1	7158	2360.2	2.11	0.6	49
1994	88-58	56.636	-165.834	F1	1650	573.9	2.59	0.71	47.6
1994	89-56	57.343	-165.24	F1	4500	1554.2	2.06	0.6	49
1994	89-57	57.008	-165.218	F1	4908	1844.1	1.72	0.51	25.9
1994	89-58	56.675	-165.211	F1	4872	2495.7	1.89	0.61	51.7
1994	89-68	56.665	-166.416	F1	1065	601.6	2.7	0.75	44.4
1994	89-69	56.991	-166.461	F1	7326	3296.1	2.03	0.6	44.5
1994	89-70	57.327	-166.485	F1	3583	1299.9	1.85	0.58	44.7
1995	88-58	56.674	-165.893	F1	2005	800.1	2.5	0.69	42.6
1995	88-59	57.001	-165.86	F1	5452	1940	2.08	0.61	48.3
1995	88-60	57.335	-165.867	F1	5041	1560	2.19	0.66	42.5
1995	89-52	57.342	-165.235	F1	8023	2162	2.3	0.69	44.9
1995	89-53	57.014	-165.218	F1	5330	1080	2.22	0.65	47.5
1995	89-54	56.675	-165.207	F1	4138	1120	2.25	0.64	50.6
1995	89-66	56.652	-166.434	F1	9517	3150	2.15	0.64	47.4
1995	89-67	56.991	-166.464	F1	6224	1640.1	2.26	0.66	48.2
1995	89-68	57.326	-166.482	F1	10720	1620	1.66	0.51	45.3
1996	88-48	57.325	-165.234	F1	4776	1580	1.92	0.56	43.6
1996	88-49	57.018	-165.213	F1	4757	1810	1.92	0.56	45.4
1996	88-50	56.679	-165.22	F1	4276	2435	2.11	0.62	48.1
1996	88-62	56.683	-166.399	F1	939	476.4	1.74	0.53	39.8
1996	88-63	56.995	-166.453	F1	7241	2510.1	2.46	0.65	45
1996	88-64	57.315	-166.494	F1	4273	1600	1.98	0.58	41.9
1996	89-59	56.632	-165.827	F1	4137	750	2.16	0.61	47.3
1996	89-60	56.997	-165.838	F1	5502	1270	2.29	0.67	41.4
1996	89-61	57.318	-165.867	F1	4719	1640	1.93	0.6	44.5
1997	88-48	57.336	-165.24	F1	5327	1585	2.32	0.66	49.2
1997	88-49	57.006	-165.217	F1	4650	1030.1	2.5	0.69	52.1
1997	88-50	56.672	-165.231	F1	6330	1580	2.52	0.7	47.8
1997	88-62	56.663	-166.435	F1	2928	1740	2.52	0.67	48
1997	88-63	56.985	-166.468	F1	7047	1920	2.27	0.66	45.9
1997	88-64	57.328	-166.487	F1	5913	1850	2.24	0.53	44.9
1997	89-60	56.643	-165.835	F1	4864	1250	2.32	0.64	48
1997	89-61	56.988	-165.852	F1	5293	2520	2.22	0.65	44.8
1997	89-62	57.322	-165.872	F1	2488	1166.9	2.55	0.79	42.1
1998	88-62	56.639	-163.823	F1	3009	1080	2.75	0.71	52.1
1998	88-63	56.983	-162.856	F1	4130	1698.6	2.02	0.52	51.3
1998	88-64	57.313	-165.873	F1	2605	780.1	2.27	0.62	44.4
1998	89-44	57.343	-165.253	F1	6152	959.8	2.17	0.6	48.8
1998	89-45	57.009	-165.22	F1	4164	1161.8	2.14	0.61	48.7
1998	89-46	56.675	-165.219	F1	5422	1814.8	2.09	0.58	51.8
1998	89-58	56.655	-166.432	F1	3970	709.9	1.97	0.51	52
1998	89-59	56.99	-166.464	F1	5745	1660	2.43	0.64	53
1998	89-60	57.324	-166.482	F1	6795	2700	2.11	0.61	49.5

(Table 22 Continued)

Year	Trawl	Latitude	Longitude	Area	Abundance	Biomass	Diversity	Evenness	CPUE
1999	88-60	57.349	-165.873	F1	4373	1211	2.67	0.67	49
1999	88-61	57.011	-165.833	F1	3974	1228	2.52	0.65	53.8
1999	88-62	56.681	-165.855	F1	3636	763.6	2.75	0.69	51.1
1999	89-46	56.656	-165.215	F1	6613	1790	2.4	0.65	53.3
1999	89-47	56.987	-165.216	F1	6489	1766	2.38	0.65	48.4
1999	89-48	57.321	-165.233	F1	3368	655.4	2.36	0.64	19.8
1999	89-62	57.348	-166.484	F1	5260	1328	2.35	0.67	50
1999	89-63	57.012	-166.464	F1	3997	1305	2.83	0.75	50.9
1999	89-64	56.678	-166.436	F1	1979	576.8	2.54	0.58	52.5
2000	88-77	57.326	-165.229	F1	3470	980	1.98	0.54	49.2
2000	88-78	56.996	-165.223	F1	4330	1390	2.05	0.57	48.5
2000	88-79	56.665	-165.219	F1	3299	1125	2.2	0.6	49.5
2000	88-82	56.665	-166.436	F1	2789	1220	1.82	0.49	49.3
2000	88-83	56.996	-166.469	F1	3160	1010	2.63	0.73	50.4
2000	88-84	57.33	-166.491	F1	6249	3218	2.18	0.6	47.5
2000	89-70	57.345	-165.867	F1	4009	2412	2.15	0.6	45
2000	89-71	57.009	-165.852	F1	2952	924.1	2.14	0.58	47.1
2000	89-72	56.676	-165.842	F1	2197	535.1	2.5	0.65	48.8
1990	37-102	58.32	-169.121	F2	17904	2494.6	0.79	0.27	47
1990	37-103	58.666	-169.202	F2	58824	1755.4	1.68	0.58	48.2
1990	78-100	58.015	-168.457	F2	13017	2603.8	1.96	0.55	52.6
1990	78-101	58.369	-168.468	F2	9719	2717.1	1.54	0.46	48.6
1990	78-102	58.695	-168.487	F2	10215	1401.8	2.04	0.58	45.5
1990	78-113	58.645	-169.778	F2	2951	79.1	0.26	0.08	48
1990	78-114	58.326	-169.733	F2	5248	1542.2	2.29	0.62	47.7
1991	37-95	58.325	-169.115	F2	3240	1088.7	2.03	0.59	32.6
1991	37-96	58.663	-169.16	F2	6066	1437.8	1.26	0.39	32.2
1991	78-100	58.662	-168.488	F2	9096	1601.2	1.92	0.64	46.7
1991	78-101	58.327	-168.469	F2	13866	2653.6	1.82	0.6	45.5
1991	78-125	58.005	-169.71	F2	8752	1355.6	1.5	0.64	48.7
1991	78-126	58.356	-169.745	F2	2659	371.2	1.82	0.6	48.6
1991	78-127	58.687	-169.804	F2	4417	563.5	0.79	0.24	47.3
1992	37-98	58.68	-169.788	F2	1265	427	1.76	0.57	30.7
1992	37-99	58.346	-169.118	F2	2830	1033.2	1.89	0.6	39.4
1992	37-100	58.011	-169.072	F2	4550	1406.1	1.47	0.46	42.7
1992	87-83	58.327	-168.432	F2	8802	3084.4	1.62	0.49	35.6
1992	87-84	58.668	-168.498	F2	2943	1131.6	1.86	0.55	28.7
1992	87-85	58.667	-169.157	F2	4408	1220	2.2	0.64	20.5
1992	87-86	58.343	-169.743	F2	2332	572.5	1.91	0.52	33.6
1993	88-96	58.679	-169.186	F2	2466	1477.5	2.34	0.74	50
1993	88-97	58.355	-169.136	F2	4308	1297.4	1.71	0.51	48.7
1993	88-98	58.018	-169.055	F2	12305	1754.6	1.16	0.35	38.1
1993	89-88	58.687	-168.493	F2	9805	1350	1.47	0.45	49.3
1993	89-89	58.345	-168.47	F2	10072	2553.7	1.68	0.5	48.7
1993	89-90	58.009	-168.43	F2	8032	2753.3	1.83	0.55	49

(Table 22 Continued)

Year	Trawl	Latitude	Longitude	Area	Abundance	Biomass	Diversity	Evenness	CPUE
1993	89-111	58.328	-169.736	F2	2892	1351.7	2.43	0.74	50.5
1993	89-112	58.651	-169.781	F2	1242	1117.3	2.1	0.69	51.4
1993	89-113	58.989	-169.828	F2	2072	1347.3	2.4	0.76	58.1
1994	88-99	58.666	-169.796	F2	3393	939.8	2.05	0.59	48.1
1994	88-100	58.342	-169.745	F2	5646	1572.2	1.67	0.5	46.3
1994	88-101	58.006	-169.699	F2	3168	1505.9	2.21	0.59	44.8
1994	89-81	58.002	-168.411	F2	10915	2710	1.27	0.39	44.5
1994	89-82	58.329	-168.49	F2	4237	958	1.8	0.55	43.4
1994	89-85	58.665	-168.453	F2	3704	1038.2	1.95	0.59	45.1
1994	89-86	58.988	-168.631	F2	14032	3210.3	0.79	0.25	44.1
1994	89-100	58.676	-169.149	F2	5646	1572.2	1.67	0.5	45.3
1994	89-101	58.34	-169.111	F2	3168	1505.9	2.21	0.69	44.2
1994	89-102	58.021	-169.07	F2	2939	1726	2.19	0.72	45.1
1995	88-89	58.677	-168.483	F2	10083	1565	2.03	0.63	41.1
1995	88-90	58.354	-168.455	F2	3988	1390	2.03	0.63	47.2
1995	88-91	58.017	-168.43	F2	10177	2870	1.52	0.46	45.8
1995	88-111	58.007	-169.728	F2	4885	1785	1.68	0.53	46.8
1995	88-112	58.331	-169.766	F2	1949	559.6	2.46	0.68	46.9
1995	88-113	58.653	-169.799	F2	11234	692.3	0.66	0.19	46.6
1995	89-101	58.67	-169.162	F2	3144	1611	1.86	0.56	39.6
1995	89-102	58.346	-169.12	F2	2854	1360	2.25	0.66	48.4
1995	89-103	58.018	-169.058	F2	3053	2227.7	1.69	0.53	19.1
1996	88-92	58.998	-169.234	F2	6370	1881	1.82	0.54	45
1996	88-93	58.682	-169.133	F2	5252	1680	1.92	0.58	47
1996	88-94	58.332	-169.109	F2	6342	2886	2.02	0.63	47.9
1996	88-95	58.006	-169.06	F2	3917	1814	2.24	0.67	55.2
1996	89-90	58.677	-168.497	F2	4790	1417	1.29	0.41	47.5
1996	89-91	58.343	-168.458	F2	5482	2500	2.06	0.63	52.5
1996	89-92	58.008	-168.434	F2	5511	2370	1.36	0.41	39.8
1996	89-113	58.325	-169.724	F2	4974	2150	1.59	0.51	50.5
1996	89-114	58.658	-169.781	F2	2276	840	1.78	0.54	48.7
1996	89-115	58.987	-169.83	F2	4243	1570	1.69	0.52	48.5
1997	88-88	58.002	-169.068	F2	4952	2740	2.48	0.68	47.5
1997	88-89	58.31	-169.116	F2	3790	1705	2.24	0.64	46.9
1997	88-90	58.643	-169.133	F2	2596	1350	2.01	0.58	44.4
1997	88-91	58.995	-169.197	F2	5527	1220	2.22	0.64	47.2
1997	89-88	58.325	-168.471	F2	3987	1410	2.28	0.68	43.6
1997	89-89	58.658	-168.498	F2	9086	1920	1.73	0.54	45.5
1997	89-107	58.682	-169.781	F2	2011	766.1	2	0.6	48.9
1997	89-108	58.348	-169.735	F2	2672	1000.2	1.74	0.54	50
1997	89-109	58.016	-169.698	F2	7381	2780	1.37	0.42	45.1
1998	88-103	58.3	-168.47	F2	3357	1120	1.92	0.49	51
1998	88-104	58.649	-168.499	F2	3825	1180	1.69	0.52	44.6
1998	88-105	58.989	-168.539	F2	3830	990	1.4	0.42	45.8
1998	88-114	58.685	-169.786	F2	1467	600	1.6	0.47	49.5

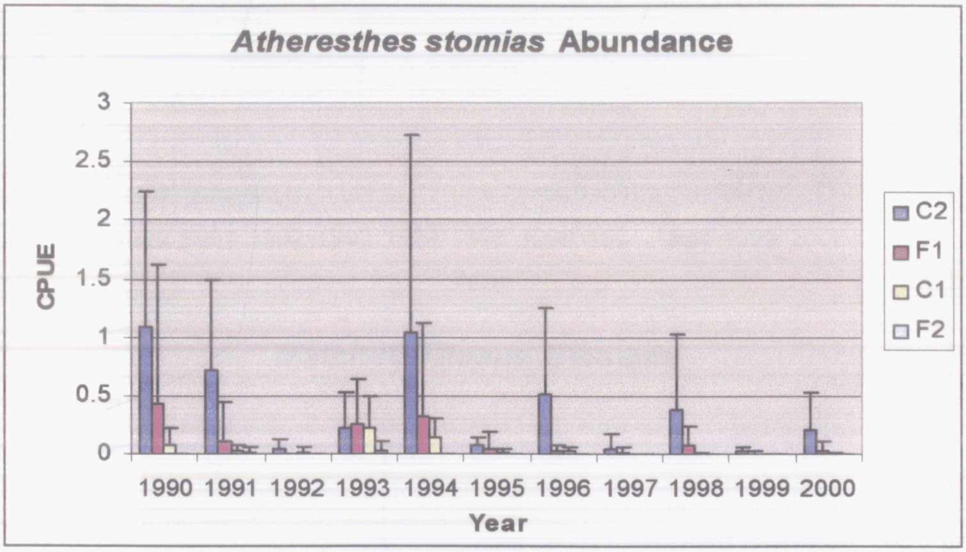
(Table 22 Continued)

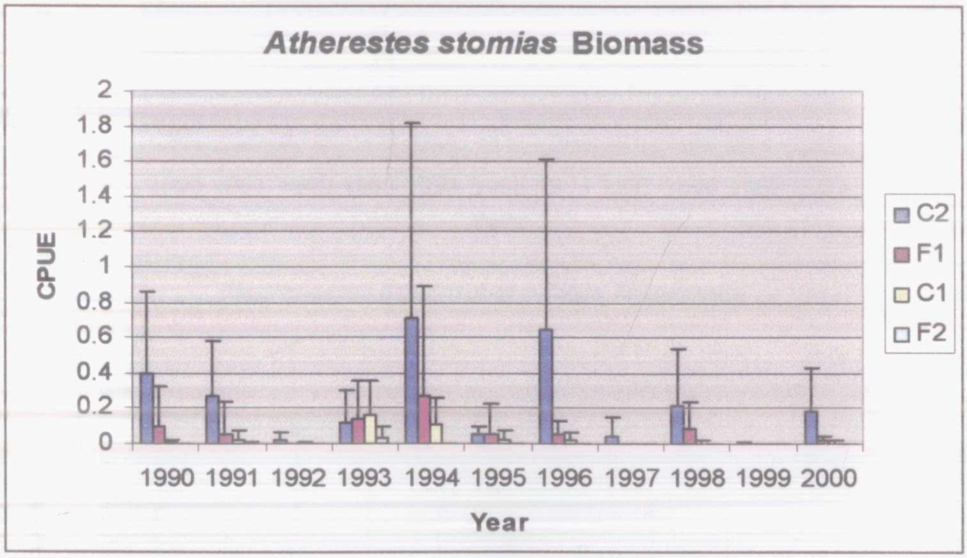
Year	Trawl	Latitude	Longitude	Area	Abundance	Biomass	Diversity	Evenness	CPUE
1998	88-115	58.347	-169.727	F2	2486	907.5	1.4	0.42	50.4
1998	88-116	58.015	-169.709	F2	2543	1110	1.67	0.53	48.5
1998	89-97	58.325	-169.116	F2	4353	840	2.04	0.56	63.1
1998	89-98	58.658	-169.149	F2	7631	1000	1.73	0.49	47.5
1998	89-99	58.992	-169.18	F2	7224	1410	2.22	0.64	48.9
1999	88-90	58.674	-168.512	F2	1916	619.1	1.83	0.52	44.7
1999	88-91	58.349	-168.474	F2	1794	72	2.09	0.63	46.3
1999	88-92	58.014	-168.438	F2	4508	2023.1	1.81	0.56	38.2
1999	88-113	58.324	-169.721	F2	4914	1830	1.01	0.31	46.5
1999	88-114	58.655	-169.775	F2	620	348.4	2.13	0.61	46.6
1999	88-115	58.984	-169.815	F2	455	334.4	2.27	0.65	48
1999	89-92	58.677	-169.148	F2	4393	525.1	1.53	0.43	50
1999	89-93	58.342	-169.112	F2	6734	2010	1.87	0.53	50.7
1999	89-94	58.01	-169.067	F2	4284	2230	2.23	0.63	50.7
2000	88-116	57.987	-169.036	F2	3037	1290	1.46	0.43	48.8
2000	88-117	58.316	-169.115	F2	3425	791.3	1.65	0.47	53.2
2000	88-118	58.654	-169.145	F2	3342	1037.2	1.85	0.56	49.2
2000	88-119	58.975	-169.169	F2	3739	1678.6	2.07	0.62	48.2
2000	89-89	59.009	-168.534	F2	6522	1204	1.85	0.54	44.6
2000	89-90	58.67	-168.512	F2	13057	1176	0.99	0.28	43.9
2000	89-91	58.346	-168.475	F2	4442	1094	1.83	0.51	48.6
2000	89-92	58.012	-168.439	F2	6227	3493.8	1.64	0.5	39.1
2000	89-109	57.99	-169.7	F2	3266	988.7	1.52	0.43	45.9
2000	89-110	58.326	-169.734	F2	6450	1648	1.69	0.49	45.4
2000	89-111	58.656	-169.783	F2	2910	788.8	1.73	0.51	45.2
2000	89-112	58.989	-169.843	F2	2285	1034.4	2.28	0.64	45.9

Appendix 9: Graphs of Abundance and Biomass of Dominant Species. Changes in abundance, if measured, and biomass of dominant species are shown for each area between the years 1990 and 2000. Species shown were significantly different for the interaction term of area*year.

Figure 6: Graphs of Dominant Species

Piscivores





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